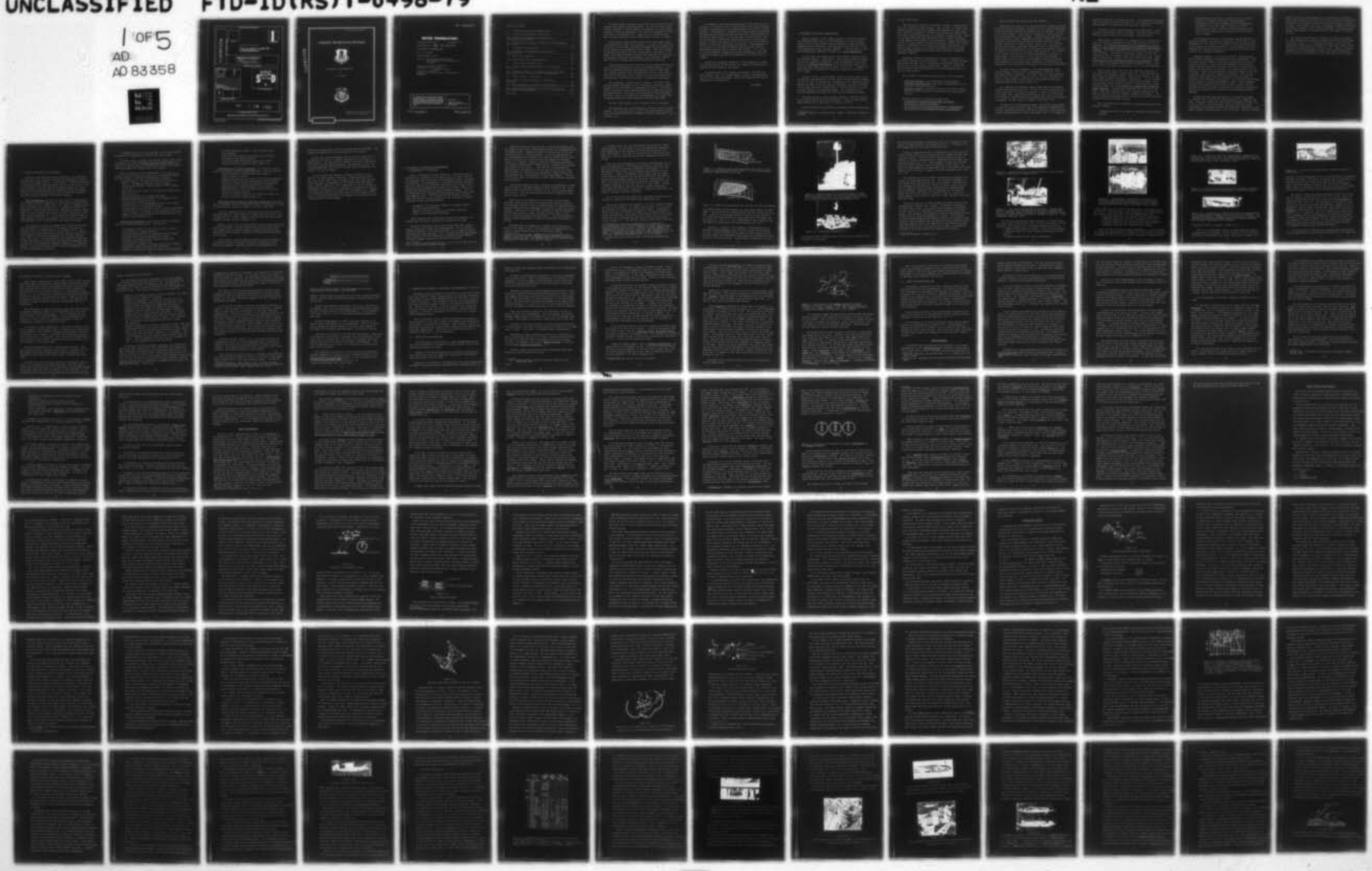
AD-A083 358 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/4
ELECTRONIC COUNTERMEASURES,(U)
AUG 79 A RAZINGAR
UNCLASSIFIED FTD-ID(RS)T-0498-79 NL

1 OF 5
AD
AD83358



PHOTOGRAPH THIS SHEET

AD A083358

DTIC ACCESSION NUMBER

LEVEL

INVENTORY

FTD-ID(RS)T-0498-79

DOCUMENT IDENTIFICATION

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☑
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A		

DISTRIBUTION STAMP

DTIC
ELECTE
APR 24 1980
S D
D

DATE ACCESSIONED

80 1 29 105

DATE RECEIVED IN DTIC

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDA-2

DTIC FORM OCT 79 70A

DOCUMENT PROCESSING SHEET

FTD-ID(RS)T-0498-79

FOREIGN TECHNOLOGY DIVISION

ELECTRONIC COUNTERMEASURES

by

A. Razingar

FTD -ID(RS)T-0498-79

EDITED TRANSLATION

FTD-ID(RS)T-0498-79 30 August 1979

MICROFICHE NR: FTD-79-C-001199

ELECTRONIC COUNTERMEASURES

By: A. Razingar

English pages: 386

Source: Elektronska Protivdejstva, Vojnoizdavacki Zavod, Beograd, 1971 pp. 5-347

Country of origin: Yugoslavia
Translated by: Scitran
F 33657-78-D-0619
Requester: FTD/SDEC
Approved for public release; distribution unlimited.

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

Table of Contents

I. Electronic Actions and Counteractions.................. 3

II. Military Applications of Electronics................... 9

III. Influence of Electronic Countermeasures on Development of Electronics.................................... 13

IV. Characteristic Examples of Electronic Countermeasures in the Past.. 27

V. Electronic Reconnaissance................................ 108

VI. Electronic Countermeasures Against Means of Communications.. 141

VII. Radar Countermeasures.................................. 173

VIII. Intentional Radar Countermeasures..................... 219

IX. Passive Radar Countermeasures........................... 253

X. Change in Radar Reflex Surface of the Observed Object... 282

XI. Geometrical Shape in the Design of the Object Under Observation and Its Effect on Radar Countermeasures.......... 324

XII. False Targets - Radar Baits............................ 351

XIII. Effect of Nuclear Explosions on Electronic Equipment.. 360

XIV. The Destruction of Electronic Installations........... 370

XV. Construction Conception of Electronic Equipment and Its Effect on Countermeasures............................. 376

References.. 385

In modern armies, electronics represents the main means for commanding troops and for directing combat. All types of armed forces utilize thousands of various complex installations for radio, radar, computers, television and others. The electronic equipment for military needs is increasing daily. Today there are hardly any weapons in which electronics is not represented in one way or another.

Broad military applications of electronics have brought about a new problem for science and technology: to paralyze the operation and effects of the enemy's electronic equipment and thus deprive him of his capability to command and direct combat. There are a number of measures and methods that can be used against electronics of the enemy. New tactical methods that have been developed are electronic surveillance, electronic countermeasures, and electronic defense, each of which is finding more and more application every day.

The operational staff of units that use electronics must be familiar with the characteristics of the interfering signals, so that they can undertake effective countermeasures within a short time. It is equally important that the operational staff of other units — which may be the object of the electronic action and counteraction interference — understand the elements of electronic interference.

This monograph is divided into 15 chapters. The first three contain general explanations of the influence of electronic countermeasures on the development of technology and tactics. The fourth chapter represents a more thorough description of electronic actions and counteractions in the past, and particularly during the Second World War. The rest is related to the methodology of various types of counteractions and useful directions for their application.

The last, 16th chapter, lists literature used by the author.

The historical part is based mainly on the data from the Western sources. The reason for this is lack of data from eastern war operations and great differences in methods of warfare (distances, use of airpower, etc.).

The monograph "Electronic Countermeasures" represents the first attempt in our country to give presently known sources and methods of electronic countermeasures in an understandable form and in a logical sequence. The monograph is intended for a broad group of experts who are concerned with the construction, utilization, and application of electronic installations. At the same time, it may prove very useful for engineers constructing objects which will be or may be the objects of radar surveillance and for all those that are involved in methods of electronic surveillance and disguise. The monograph can also be used as a textbook in schools where electronics and its application represent one of the basic disciplines. It is written in an understandable language using simple mathematical tools with diagrams and graphs and should be understood by a broad circle of readers.

Because this monograph represents a first attempt at a comprehensive presentation on this matter, all comments, remarks and suggestions will be welcome by the author.

The author would like to express his thanks to the Prof. Dr. Janez Dekleva, Prof. Dr. Vladimir Matkovic and Mr. Alexander Mutavdzic for very useful discussions, advice and suggestions during the preparation of the manuscript.

THE AUTHOR

I ELECTRONIC ACTIONS AND COUNTERACTIONS

When, on August 8, 1940, Germans decided to give Great Britain the deciding blow and force it into capitulation by their airforce attack, none of their military experts suspected a complete failure. Appearing on the horizon was a new dimension of the war which in its later operations became ever more important – the electronic actions and counteractions, popularly referred to as <u>the electronic war</u>.

At that time, the Germans had at their disposal the main factor for attaining success – superiority. Great Britain could not compensate for its momentary inferiority in men and materials in any other way but to <u>increase the efficiency</u> of its insufficient means of warfare, and thus change the ratio of forces in its favor. A subtle but powerful means for opposing the German war machine at that moment was – radar.

By use of radar, an extraordinary sensor for a new system of air surveillance and information, the RAF (British Royal Airforce) command was able to build an organization (remarkable at the time) which could deprive the enemy of all the surprise advantages, provide an estimate of his forces and their concentration at a given place and at a given time and related to the immediate danger. The efficiency of the British (numerically smaller) air force was thus magnified tenfold.

The prime minster of Great Britain, Winston S. Churchill stated in the Lower House at the end of the battle: "Never in the field of human conflict was so much owed by so many to so few."*

With the Battle of Great Britain, electronic warfare was born and

---

* Winston Churchill, First World War, Volume II, page 313, Prosveta, Beograd.

is still alive today.

"The electronic warfare" is difficult to define. Among the military, this concept has many meanings. Some consider it to mean "commanding" armies by electronic computers and programs for every activity. Others are reducing it to just active and passive interference with radar stations and possibly to the means of communications. There are few that understand that electronic warfare actually represents a large number of new methods, new installations, weapons and systems, as well as a great number of tactical procedures, measures and countermeasures. Therefore, we will define the concepts of electronic warfare by known, recognized and simple expressions which will become clear and understandable to the reader after carefully reading the subsequent chapters.

Electronic warfare is represented by a group of technical and operational measures with two objectives. First, to prevent the enemy from using electronic waves, to diminish his efficiency when using them or even use his own waves against him. Second, to assure for our own forces a free and effective use of electromagnetic waves in spite of enemy actions.

The activities of electronic warfare may be listed as follows:

- <u>electronic activity</u> (basic application of electronics).
- <u>electronic counteractivity</u> (electronic countermeasures to prevent basic electronic activity).
- <u>electronic defense</u> (electronic counteractivity and electronic defense of basic electronic activity from electronic counteractivity).

The main properties of electronic warfare are:

- <u>universality of applications and range of activity</u>
- <u>the activity is instant and subtle</u>
- <u>the technology used in electronic warfare is undergoing an exceptionally fast development and rate of obsolescence</u>.

These properties are derived from the following:

Electronics has found its way into all aspects of modern military activities, from the telephone, proximity fuse and radar installations to the complicated offensive and defensive missile systems. The area of their use includes a wide range of frequencies (from the very low part of the spectrum to the IR range). Introduction of electronics into the military systems (commanding, guidance, navigation, etc.) and systematic interconnections between the military and the civilian systems (control of air traffic, public alarms, etc) are every day increasing the region, importance and universality of electronics. The character of propagation of the electronic waves enables electronic warfare to be carried out on a very large territory. Thus electronics affects the utility of certain installations or systems or applications of certain tactics at the scene of war operations. A clever enemy can also utilize various anomalies which occur during the propagation of electronic waves (reflections, diffractions, and refractions) and thus increase the surprise and the range of activities.

The great speed of propagation of the electromagnetic waves (300,000 km/sec) provides almost instantaneous realization of all electronic warfare activities. The "time" factor is thus eliminated and the enemy can almost instantly react to the basic electronic activity (as for example, indiscretions in the network connections, inadequate application of the system, etc.).

The equipment and procedures used in application of electronic warfare neither destroy nor kill. In fact it is not always necessary to kill the enemy to prevent his activity. A bomb or a missile may, for example, have a great destructive ability, but is of little use if its means of transportation are paralyzed due to lack of navigation or guidance, and thus cannot be brought to the proper site.

The means for interfering with radar, installations for guidance of missiles, neutralizing and creation of confusion in communication systems, diverting projectiles from their trajectory, anti-electronic disguise and simulation of objects and targets, etc. is in modern war,

equally as necessary as firing activities. The consequences of battle will be damaging to the one that does not use electronics (as has been demonstrated in the Second World War and later conflicts).

Electronic warfare, which continues, has brought about a great advance of electronics as well as science. Only the science of explosives (nuclear bombs) can "brag" about a similar advance.

Superiority in electronics as a prerequisite for successful warfare is essentially different from the usual estimate of military dominance. The determining factor for this superiority is not the number of installations, but frequency of discovery of new fields of activity. The initial resistence of a system provides only a temporary advantage. Resistance of electronic systems to electronic counteractivities is becoming smaller and smaller every day. Superiority in electronics requires, more than in the other areas, technical surprises and a continuous search for such surprises. There is no room for a slowdown which does not only mean a loss in superiority, but at the same time represents a loss in men and materials.

When an enemy learns about tactical-technical properties of such weapons as airplanes, cannons tanks, etc., that knowledge does not render such equipment useless. When, on the contrary, an enemy learns about technical properties of electronics -- as, for example, the system VOJIN (air surveillance, reporting and guiding), navigation systems, missile guidance systems, certain networks or communication systems etc. it is illusory to consider such systems any longer operative. The uncovered system may even be of use to the enemy. They must disappear and be most urgently replaced (by new means in the sense of using technical solutions and methods). This is one of the most important and at the same time the most expensive characteristics of electronic warfare.

Thus, the objectives of electronic countermeasures may be formulated as follows:

- a maximum paralysis of the enemy's electronics and electronic systems.

- assuring maximum resistance of electronics and electronic systems to the enemy's electronic countermeasures,
- introduction of discrete disorganization, disinformation, and anarchy in the vital enemy's electronic systems.
- redirecting the enemy's activities and protecting the own activity by the application of electronic deceit and electronic disguise.

The activities in electronic warfare depend upon developments of technical knowledge and electronic technology, and the fact is that improvements in the science of electronics occur daily largely due to the existence of electronic warfare. As a consequence, it may be concluded that electronic warfare is not related to any actual war activity, but continues indefinitely.

Electronic warfare i.e. electronic activity, countermeasures and electronic defense is being given ever more significance. There is an ever greater number of electronic installations, articles in scientific journals in this area, and statements of the military experts that the superiority in future wars will be largely determined by the superiority in the ether. This superiority is not easy to achieve. Aside from the material difficulties related to men and technology, which could be regarded as subjective, there are the objective difficulties which are reflected in the very nature of electronics and electronic installations. All electronic installations either radiate or recieve electromagnetic waves. Free propagation of these waves enables easy detection of their sources, and thus information about the method of operation of electronic installations. This in turn facilitates the application of corresponding countermeasures.

Because the small countries have less developed electronics for military uses, they have an inferior position in electronic warfare. This does not mean that they cannot do anything in this area for their safety. Even with modest means but giving very great significance to electronic defense and operation of electronic systems under intensive countermeasures, a lot can be done. Special attention

should be given to the development of installations for electronic defense and training of the staff and crew for electronic installations and systems to work under conditions of intensive electronic countermeasures. Thus operators and crews (equipped with adequate means) can be trained to respond to any situation, introduce the proper countermeasures and paralyze the expected effect of the enemy's electronic activity.

The methods and equipment for carrying out electronic warfare are (for understandable reasons) carefully guarded and are developed in greatest secrecy. It is therefore difficult to write and talk about modern installations and methods for electronic warfare without specific, verified data which are hard to find. However, systematic examination of the development of modern electronic technology can give a picture of the possibilities and some forms of such warfare.

II MILITARY APPLICATIONS OF ELECTRONICS

Electronic installations represent generally a very important, necessary and a very large part of modern war technology (in units of all types of armed forces). At the present, it would be difficult to name any military installation that does not use at least a little electronics. The main military electronic groups are: radio, radar, television installations, installations for directed communications, for infrared technology, and for electronic navigation and also electronic guidance and direction systems.

Radio installations are still the only means of communications which enable continuous commanding for modern units of high mobility. Use of aviation, navy, armored units, etc. cannot be imagined without good and reliable radio communication. Introduction of radio communications in lower units and even for individuals requires a large number of radio equipment which varies in power, sensitivity, frequency ranges, modulation etc. On the other hand, numerous types of radio equipment require a considerable radio discipline and special installations for fast retransmissions and coding of messages.

Installations for directed communications provide radio communication where the emission and the receiving of the electromagnetic energy is radiated within a narrow beam (1-13°). Such installations use high frequencies and special antennae, and because of the nature of their wave propagation they use relay stations along their routes. Directed communications combine the advantages of both radio and wire transmissions and provide simultaneous transmissions of a large number of telegraph, telephone, or TV channels. Because of the directed nature of this type of electromagnetic radiation, eavesdropping is difficult.

If communications in the army represent its "nervous network" then means for reconnaissance represent the "army's eyes".

The radio, radar, television and infrared (laser) means of reconnaissance (in short, electronic means for reconnaissance) are receiving in modern armies ever bigger roles along with the photographic equipment and reconnaissance of all spectra.

Radar installations either independently or as a part of a system, enable the following operations to be carried out during the day or night or under poor meterological conditions:

- reconnaissance of air space and discovery of targets in the air. Tracking and identification of targets.
- directing and guiding of fighter planes to their targets in the air.
- directing fire of all types of AA artillery to their targets in the air.
- giving navigational aid to planes and ships.
- directing and guiding projectiles to the targets on the ground, on the sea and in the air.
- reconnaissance of the battleground from the air or ground and directing fire at the ground targets.
- reconnaissance of the ground or the sea surface and directing fire of weapons to the targets on the ground or on the sea.
- prompt and total presentation of the instantaneous air situation, timely reporting, etc.

Television installations, while relatively new, are finding every day new military applications. They provide:

- observation of results of the air or artillery strikes and informing the command instantly.
- continuous observation of the battlefield and the enemy background and instant informing of the status.
- observing and recognizing the artillery targets and correcting the artillery fire.
- transmission of documents, drawings, tables, etc. between headquarters (which increases their efficiency).
- underwater observations, defense of harbors from submarines

and other underwater attacks, search for mines and sunk torpedoes.

- televised observations of the ground using airplanes, helicopters, and unmanned gliders.
- televised guidance and flight correction of guided missles in the last phases of their flight, etc.

Installations for infrared technology, like television installations are getting increased applications daily. They are used for:

- night observations, reconnaissance and aiming at short distances (1000 m).
- leading projectiles to the source of the infrared radiation.
- passive or active infrared observations of the territory and objects on the ground from airplanes, helicopters or unmanned gliders, using photography or electronics.
- application of the narrow infrared rays for controlling defense of objects and roads.
- use of the directed infrared rays (optical or laser) as a carrier of directed communications, etc.

Installations and systems for electronic navigation assure guidance of airplanes, ships and submarines either in following their route or arriving at the target area (under all weather conditions).

Electronic installations for guidance and direction are used to guide projectiles to their targets, to steam gliders during the critical phases of their flight (landing, firing of missiles) and to guide unmanned airplanes (using TV cameras, etc.).

Because of their ever increasing speeds (and slow human reactions) electronic equipment is being introduced into these systems which is also equipped with electronic computers (analog and digital types). Interference with electronic installations thus paralyzes operations of the system.

At the present, even the smallest military operations cannot be successfully carried out without satisfactory operation of their electronic equipment. Therefore, electronic countermeasures are

receiving attention equal to that of introduction of electronics. New methods and equipment are being developed for this purpose.

On the basis of these examples (which are by no means all), it is apparent that there is a general application of electronics in modern armies. This application is rapidly increasing, particularly for gliders and high speed projectiles, and generally for ever increasing maneuvering capabilities of various types and branches, and thus for the army as a whole.

For a relatively new branch of science, electronics is in a state of fast and continuous evolution. During the Second World War, this science (which was very young at the time) gave the armed forces the means, the equipment and the methods that represented great technical surprises. Their application in the war resulted in significant changes in tactics, strategy and conceptions of warfare. Its present day progress is so great that (according to the judgment of the American and Soviet military experts) future warfare in relation to the Second World War can be compared to the relation of the Second World War to the Crusades.

III INFLUENCE OF ELECTRONIC COUNTERMEASURES ON DEVELOPMENT OF ELECTRONICS

Since - according to the well known rule - each action has its counteraction, electronics in the armed forces was faced, from its very beginning, with discoveries and developments aimed at disabling its operations. In the beginning of the Second World War such measures were reduced to the physical destruction of the radar, radio-navigation and telecommunication centers and stations, either by air bombing and parachutting or by using underground groups. Later on, an unremitting battle developed for the dominance of the ether using electromagnetic waves. The following factors have been accepted during that period as good indicators for the efficiency of applied electronic actions and countermeasures:

- the number of Allied planes downed by the German fighters and antiaircraft artillery.
- number of successful actions by the German submarines.
- number of the sunk German submarines.

These indicators have shown daily increases and decreases, depending upon the success and speed of reactions by the enemy.

During the Second World War, Great Britain gave great significance to electronic actions and countermeasures. On the initiative of Winston Churchill (later Prime Minister), the Air Defense Research Committee* was formed already in 1935. Churchill himself participated very actively in its work (thanks to his friend and later adviser, Frederick Lindeman, professor at the Oxford University).

---

*W.S. Churchill, Second World War, Vol. I, pp. 74, 139, 140, 143, 217; Vol. II, pp. 351,352, Prosveta, Beograd.

During the Battle of Great Britain, a special development group was formed for electronic countermeasures within the Telecommunications Development Center. Heading the group until the end of the war was a young physicist Dr. Robert Cockburn. A unit for application of the countermeasures was formed at the same time within the Air Force and was referred to as "Group 80" which was headed by lieutenant colonel E. B. Aedison. Because of the ever increasing applications of electronic countermeasures during the war, "Group 80" was expanded and renamed The Air Group 100. The scope of the countermeasure applications is illustrated by the fact that in 1944 the Air Group 100 had within its structure seven squadrons of night fighers (mosquito bombers) and four squadrons of four engine bombers. They had in their units about 10,000 people, of which about 4000 were engineers and technicians.

The British believe that their electronic countermeasures reduced the efficiency of the German bombing of Great Britain by 70%, of the German system for antiaircraft defense by 75%, and the German submarines - by 90%. They also increased the accuracy of bombing of their own air forces by 40%.

After their bitter experience of the defeat at Pearl Harbor, which was caused by poor and slow communications and poor reporting, *the Americans formed (in 1942) at Harvard University (Massachusetts) special laboratories for development of electronic actions and countermeasures. They point out that after formation of these laboratories, the Strategic Air Force, which was based in Great Britain, saved losses of about 450 planes with 4500 aviators. The Navy headquarters formed a separate department to direct the electronic operations on the sea.

The Department for Communications Between Allied Headquarters formed in the summer of 1942 a joint committee for organization of electronic counteractivities and for the electronic defense.

* Because of the poor (slow) communication systems and lack of confidence in the new technical equipment, (radar) information about the Japanese attack was late. The Japanese have found the American fleet unprepared and destroyed it by fast air attacks.

In Germany there were five specialized institutions for radio-countermeasures. The institution for eavesdropping and decoding of radio communications was founded in 1932 and had (during the war) about 3000 members. The scope of its work can be illustrated by the fact that it received each day about 20,000 communications for processing.

Unitl 1942 the development of electronic countermeasures was not given enough attention. The Germans had enough of good radar installations produced by emminent manufacturers (Telefunken, I.G. Farbenindustrie, Ghema Gesh.) and considered them sufficient for the blitzkrieg.* Largely contributing to this neglect was the competition** between the general-field marshal Erchard Milch and General Martini who was heading research on electronic countermeasures. Not until 11/14/1942 did Herman Goering assign the development of high frequency technology to the state adviser Dr. Hans Plendl. He withdrew about 1500 experts from the front and founded a laboratory associated with the factory "Telefunken". History has shown that the delay of two years could not be made up.

By the end of the Second World War, electronic war did not stop. Instead it continued in its madness and undiminished fury.

One of the characteristic examples is the "war" between aviation and antiaircraft defense. The change from propeller to jet aircraft has increased the altitude and the speed of flying. Consequently, ground radar had to increase its capabilities for high altitude and distance observations, and because of the larger effect of the "time" factor they were interconnected into more efficient anti-aircraft systems (figure 3.1). The aircraft, because of their great speed and

---

* The commission "Generalbevolmaechtigen fur die technichen" was analyzing the work of all laboratories in Germany and estimated their contribution to the front. According to their judgement, development of electronics was not necessary. The laboratories were closed and the experts were sent either to other assignments or to the front. Zur Geschichte der Radartechnick in Deutschland und Grossbritanien, ORTUNG UND NAVIGATION IV/1967 by Dr. Leo Brandt.

** A. Price: Herrschaft uber die Nacht, Bertelsman Sachbuchverlag 1968.

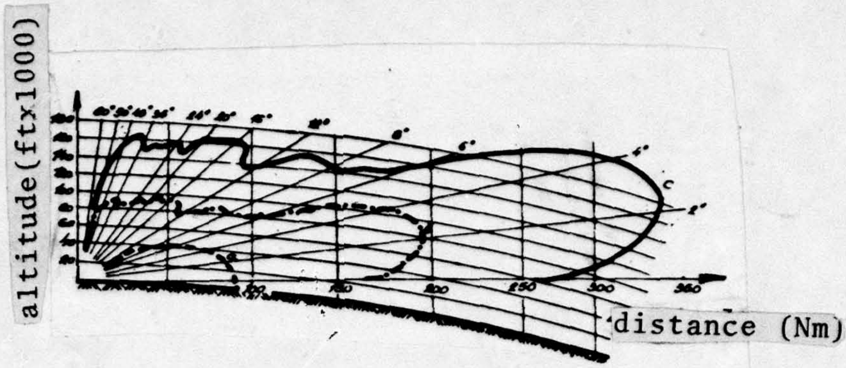


Figure 3.1. Diagram of radar radiation AN/TPS-1D a) First version (1949); b) with a modified antenna (1959); c) with modified antenna and power transmission of up to 4 MW.

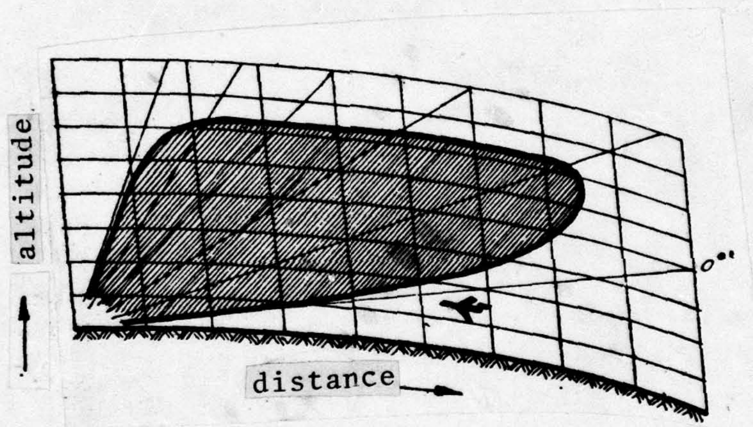


Figure 3.2. Flight of aircraft below the low limit of radar observation.

slow human actions became equipped with radar range finders and radar sights. On the ground there appeared efficient anti-aircraft missiles. Next - aircraft are using more and more low-level flying (50-300 m) i.e. below the detection limits of long range radars (Vietnamese war and Sinai war), (fig. 3.2). As a countermeasure, there appeared special radars for detection of low flying targets (fig. 3.3).

"Dornier", a company in West Germany, is experimenting with a helicopter platform <u>Do 32 K</u>, which can lift 150 kg to the altitude of 300 m. Such a platform could be used as a radar antenna carrier and would enable an exceptionally large range for detection and tracking of the low flying targets. The platform is powered by a jet en-

Figure 3.3. Detection radar for low flying targets of Dutch manufacture (model "Stola") for 70 mm anti-aircraft artillery. It is extremely mobile and covers an elevation from 0° to 35°. It has built-in measures for electronic defense (1967).

Figure 3.4. Helicopter platform DO 32 K.

gine placed between propeller rotors and the fuel is supplied from a reservoir on the vehicle.

The platform has gyroscopic stabilizers (fig. 3.4). Interest in this project is demonstrated by the information that it is financed by the West German Army and costs about 250 millions DM*.

Because of improved methods of reconnaissance as well as the dis covery of anti-radar missiles, radars and also complete systems tend to be more mobile. Even the USA army which views mobility only in relation to aircraft transportation is modifying the old systems into very mobile units (fig. 3.7). Radar computer systems were for years after the Second World War bulky and difficult to move (fig. 3.5). Today the radar-computer group approaches that of the cannon, and forms together with the vehicle a compact, efficient and highly mobile unit (fig. 3.6).

The installations for electronic reconnaissance and analysis of signals are being improved every day. The electronic equipment carried during the Second World War and a B-29 airplane laboratory has been improved and installed in a variety of planes, ships, missiles, and on satelites, which have been specialized for reconnaissance and interference. Equipped with this equipment are the American planes type B-52, B-57, B-58, U-2, EC-121, F-UCE-2 A, EA-6B, the Soviet planes of the type TU-16, MIG-21R, IL-28R, JAK-28PP, helicopter MLUR and others.

During the cold war, the United States developed the well known reconnaissance airplane, the U-2 model. According to information from the Soviet sources, this plane carried equipment for detection of radar stations on a centimeter, decimeter and meter wavelength ranges. This equipment was connected to special multichannel aircraft recorder able to record continuously for 8 hours. Later analysis of records could determine the frequency range of the overflown radar stations, pulse frequency, form and duration of the transmitted pulse, transmitter power, time of the "exposure" of the plane to the radar beam, and from all this, the analysis of the space - the method of operation of the radar stations and finally their location.

* Wehr und Wirtschaft, 1/1969, pp. 16

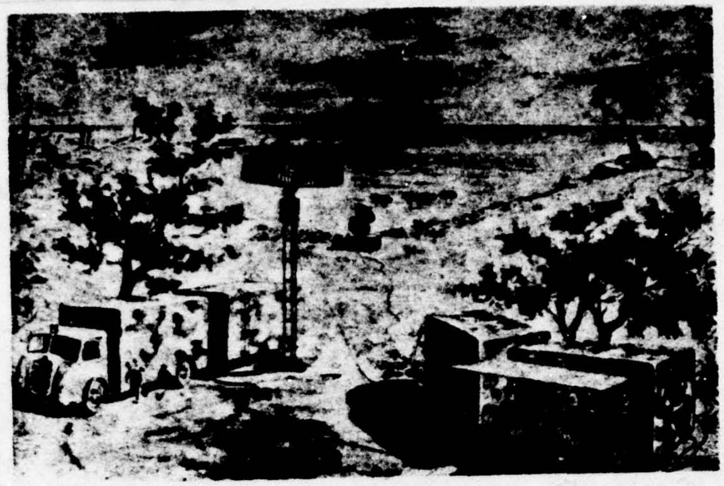


Figure 3.5. Antiaircraft battery system which has a detection radar, a computer, generators and cannons (1952).

Figure 3.6 Self-powered antiaircraft 30 mm battery "Hispano Suisa" HSS 831 A together with the radar RD 515 (detector-sighting radar with a 16 km range capable of automatic tracking of laterally flying targets at a speed of 675 m/sec and at a distance of 2000 m). It has a panoramic indicator (1967).

The tactical reconnaissance plane laboratories of model "Douglas EB-66e" which were used by the US Air Force in Vietnam in 24 hour operations were equipped with 32 different installations such as:

- 4 apparatus model ALAS for analysis of radar station impulses
- 4 apparatus model APR-14 for reception and analysis of frequencies
- 10 apparatus model ALT for active interference;

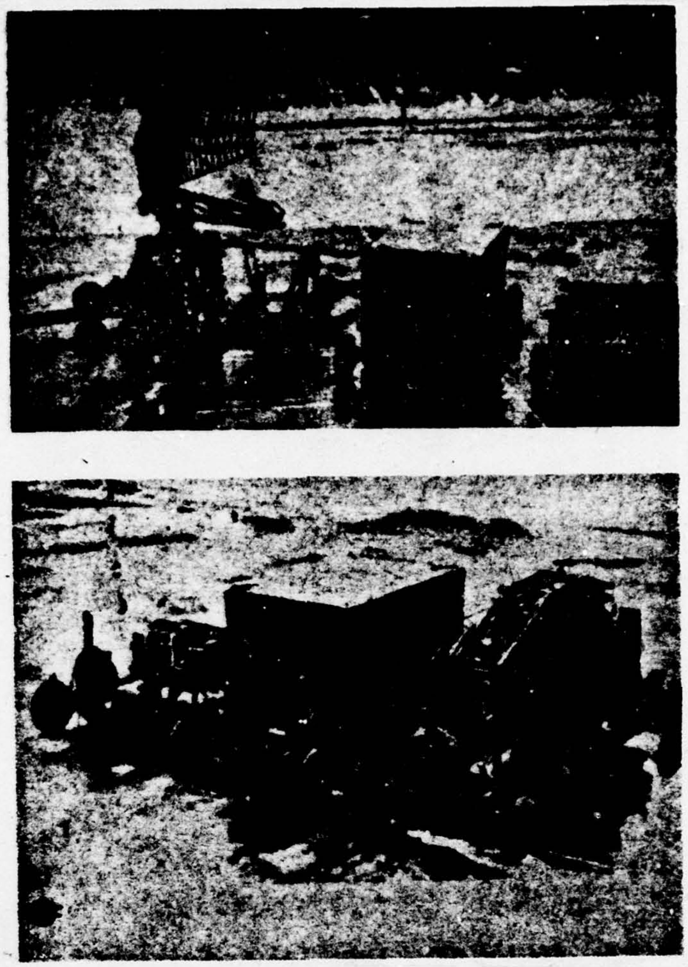


Figure 3.7. Reconnaissance radar AN/FPS-8, converted to a very mobile version AN/TPS-44 according to the USAF designs It can be changed from the marching position into its operating position and vice-versa in 20 minutes using 6 people.

2 units model ALT-12 for the 300-500 MHz range, 1 unit model ALT-16 for the 500 - 1000 MHz range, 2 units model ALT-13 for the 2500_2800 MHz range, 5 units model ALT-22 for the 2800-11,700 MHz range.

- 4 apparatus model ALA-6 for analysis of the signal impulse
- 2 apparatus model AIT for active interference with noise
- 4 apparatus model ACIQ for signaling plane radar radiation.
- 4 apparatus model AH-2 for recording radar signals.

There are other specialized plane-laboratories -- as, for example, for detection and destruction of submarines, for electronic protection and support of the fleet, for electronic protection (formation of an

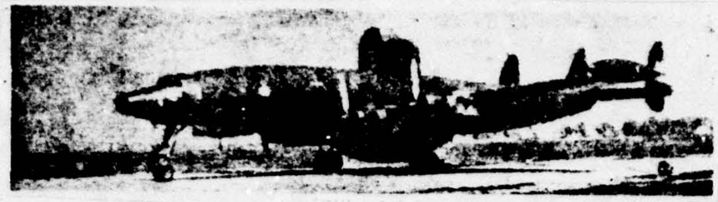


Figure 3.8. A plane for electronic reconnaissance "Lockheed EC-121 Warning Star". Used since 1950. The North Korean fighters downed one plane of this type of April 15, 1969 into the Japanese sea. This was the reason for reports about electronic syping.

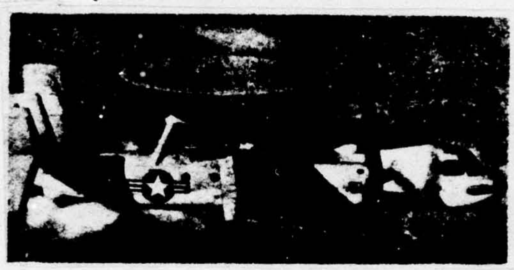


Figure 3.9 A plane of the American fleet type Grumman E-2A Hawkeye, which is used for electronic reconnaissance, defense and support.

Figure 3.10. A prototype of a plane for electronic countermeasures for the American Navy (Grumman EA-6B) with a crew of 4 members. The electronic equipment is mounted in the airplane and has special wing carriers for electronic equipment placed in containers depending upon situation requirements and assignments.

"electronic shield") of fighter - bombers, etc.

There are in development special airplane radars for lateral reconnaissance of the ground. So far, excellent results have been obtained in distinguishing the details from pictures (figure 3.11).

Figure 3.11. Picture of the ground taken by radar for lateral reconnaissance.

Parallel with these improvements, there are developments for disguising materials from radar. The amount of research done in this area can be illustrated by the report that in the USA and the FR Germany, 60 patents have been applied for during 1967 and 1968 on the matter of radar disguise of materials (these range from disguising of airplanes, missiles and weapons at their sites to disguising individuals).

The conflict between the intercontinental missiles and the systems for defense against them has in fact just started. There are missile warheads that launch false targets (missile Minuteman warheads MK 5, MK 11, MK 11 A). For the purpose of fooling the enemy, some missile carriers can launch simultaneously a number (2-15) of warheads at various targets (warheads MRV, LORV, BGRV and MK 18 for Minutemen 2 and 3 missiles). In order to disable the anti-missile defense, i.e., to reduce the time of its effectiveness, experiments are in progress using missile warheads which when entering denser atmospheres change their typical ballistic trajectories either into an extended or a cross direction. For the purpose of interfering with the radar network of anti-missile defense, missile warheads are equipped with appropriate interference devices.

For the purpose of attacking of the ground radar installations, some air-ground missiles guide themselves passively to the radar sig-

nal against which they are directed (GAM-72, Shrike).

Some missiles represent false radar targets or bait which are sent toward the radar station when an airplane finds itself within a radar beam. These missiles have the same radar-reflecting area as the carrier plane and serve to draw the anti-aircraft fire to themselves. One such missile is the "Firebee", which is 9 m long and has a wing span of 4 m. It is powered by a turboreactor engine which can develop pressures of 1000 kg. The projectile can attain a speed of 1300 km per hour and can reach altitudes of up to 30 km. The projectile can accomodate a number of passive reflectors and equipment for active interference.

The development of radar installations tends toward the direction of automatic equipment capable of self-programming its space search and selecting its optimal performance. They are equipped with all kinds of systems for electronic defense. Such installations can be utilized as a sensor part of an integrated automatic system for reconnaissance, guidance and delivery by radar.

In the area of radio-communication, there are new systems of modulation (impulse, coded-impulse, delta, accidental-noise) which transmit information in ever narrower frequency spectra and are difficult to eavesdrop on or to decode. Experiments are being made using laser rays as the carrier of information. This would enable transmission of a large number of conversations (channels) which are difficult to listen to because of their narrow beam.

The laser technology has led to manufacturing of small, light, precise and relatively inexpensive range finders. Therefore, the future weapons that require range finders should be expected to be equipped with these devices which will greatly increase their efficiency.

Infrared laser rays are being intensively investigated with discoveries of new equipment for their generation. Military experts believe that these rays could be used for destruction (burning through) of airplanes and projectiles, particularly at low altitudes. It is believed that these rays can be developed into terrible and universal

weapons, something like "death rays".

The trend toward electronic development of military equipment is of interest from a technical point of view. At a meeting*of the Electronic Industries Assn. in Washington, USA, the head of the development R.D. O'Neil presented his vision of that development for the next 10 years. The essential assumption of his visions are:

- Because of the improved systems of missile guidance, fuel consumption will be reduced to a minimum.
- Because of improvements in systems for directing fire and transfer of information, anti-aircraft artillery will significantly reduce its ammunition consumption, increase its efficiency, and thus reduce the number of their weapons.
- Equipment will be developed for the detection of explosives (mines) on basis of their chemical composition. It is anticipated that this equipment will reduce the need for armor on the lower parts of armored vehicles (tanks). It is expected that by the 1980's such equipment will be able to detect any explosives.
- Because of applications of various electronic systems, there will be manyfold increase of the battle efficiency of tanks. Against tanks, there will be effective anti-tank missiles which could be launched from the ground, airplanes, or a helicopter. These will be equipped with high quality guidance systems using computers. These developments from both sides will probably result in questionable value of the tank armor.

On the basis of modern electronic technology, one should expect that in the 1980's there will be phase modulated radar equipment of small dimensions with extremely high search speeds which will enable precise tracking of airplane bombs, artillery and mortar shells and which will be able to destroy them using precise automatic systems while they are still in the air, before they reach their targets. Because of ever increasing use of electronics in communications and radar and

*Wehr und Wirtschaft, 1/1969, pp.6.

in equipment and systems for navigation, the sensitivity to electronic counteractivity will increase. It is expected that in the future it will be possible to "turn off" the enemy radar, navigation systems and range finders (even those that use lasers) by using interference equipment which always gives a logical interference signal and thus puts given equipment or system out of action.

The reader of the above has by now obtained a picture of many purposes and trends of electronic applications in the armed forces. Electronics gives the armed forces the means, the equipment and the methods that can cause significant changes in tactics, strategy and conceptions of warfare.

It is not only the means of military electronics, offensive or defensive, that are subject to electronic countermeasures. Enormous funds are being spent for interference with the radio-diffusion transmissions*. Serving as an example is the information that in the 1960 there were on the territory of the Warsaw Pact countries about 2000-2500 transmitters for interference with the "Voice of America". The majority of these transmitters were installed on the territory of the Soviet Union, so that the Soviet listeners could receive less than 10% of these transmissions. This was the case in spite of the fact that the "Voice of America" kept increasing its emission power and changing frequencies, directing beams and undertaking other countermeasures.

Electronic warfare requires not only great technical and technological efforts, but also considerable funds, which may be suspected from some scant reports published in various scientific journals. The following data can be used to illustrate that various countries spend enormous amounts for this purpose.

After forming the Research Center for National Defense (1942), the USA has spent 300 million dollars for every war year just on the development of radar and the radio eavesdropping equipment. In 1959 the

* "Space Aeronatuics", April 1960, pp. 125, 132, 135, Ai Pozeg: Electronic interference and measures against electronic interference in anti-aircraft defense, Vazd. Ylasnik, 1961, pp. 10-13.

Year	1960.	1961.	1962.	1963.	1964.	1965.	1966.	1967.	1968.	1969.
Amount in millions of dollars	177,1	182	180	182	174	165	147	148	140	150

Table 3.1 USA budgeted expenses for development of electronic countermeasures for aircraft. From 1960-1969*

expenses reached 400 million dollars, in 1960 they reached 500 million dollars, and the budget for 1969 anticipated 730 million dollars for this purpose.

Besides these military institutions, there are in the USA over 54 companies that work on the development and manufacturing of equipment for electronic activity and countermeasures. (In the Appendix of the book, there is a list of some modern American equipment of this type).

The West German budget for 1969** anticipates expenses of 85 million DM for development on air reconnaissance. This is 20% more than is planned for the development of the Navy, and is equal to the budget for development and improvement of caterpillar vehicles.

According to the opinion of the military theoreticians, superiority in a future war will depend, on one hand, upon the superiority in the ether and, on the other hand, upon the use of equipment and installations that are not sensitive to electronic countermeasures. The duty of electronics as a science is to resolve this problem as soon and as well as possible.

The consequence of the above is work on creating substitutions, parallel equipment and systems as well as technical surprises, all with the objective of achieving equality, if not superiority over, electronics of a possible enemy.

* "Forces aeriennes francaises", 1/1961, pp. 82.

**"Wehr und Wirtschaft" No. 1/1969, pp.16.

IV CHARACTERISTIC EXAMPLES OF ELECTRONIC COUNTERMEASURES IN THE PAST

The manner and the potential of electronic activities and counter-activities should be viewed through progress of electronic technology and, generally, the military technology and from the point of view of a future war conflict. The electronic activities and countermeasures (electronic warfare) assumed a definite role during the Second World War. Because of the secrecy, it was not possible to get acquainted with this activity until the end of the conflict, and even then not completely. Therefore, experiences in this area are still insufficiently studied and known.

Here are presented a few of the most characteristic examples of these activities in the order of their time sequence and according to the branches of the military electronics. These examples could be of value and instructing even today because during peace time similar are often made inadvertently. Such errors if repeated during the war conditions could prove to be very expensive.

4.1. BEFORE THE SECOND WORLD WAR

The oldest branch of electronics is radio communications which were first developed for the needs of the Navy and only later for the ground forces and the Air Force.

Already in the Russian-Japanese war, the Russians noticed that they could easily listen to enemy radio transmissions, particularly since the messages were not coded.

During the First World War eavesdropping on the radio transmissions was greatly developed because it provided useful information about the

enemy, his plans and intentions while interferences with transmissions were neglected.

The head of the Information Department of the Austrian Headquarters (M. Ronge wrote:* "Radio eavesdropping was very valuable to our leadership. We could promptly react and thwart Russian intentions. We had an excellent understanding of the distribution of the enemy units up to the Division level."

Unsettled regulations of radio-communications and lack of radio discipline enabled easy detection and identification of units. Thus, for example, the Germans knew about the position of the 10th French Army in July 1918 because an officer mentioned it in a radio-communication. The French were following the movements of the German 193rd Division because of a constant error of its radio dispatcher who always put the number of the messages sent at the end of his dispatch.**

Codes were introduced during the First World War in order to reduce the effect of eavesdropping. Thus, for example, the Russian Supreme Command ordered on September 14, 1914 that all messages must be coded. Each branch of the British armed forces had its own code.

Discovery of the radio-goniometer in 1916 enabled determination of the position of the radio station and precise tracking of the enemy's units or ships. He was able to undertake prompt countermeasures.

Usefulness of radio-eavesdropping was proven by experiences of the First World War and thus all the armies entered the Second World War with well organized radio-eavesdropping and radio-goniometer services. (In Germany it was called "Mithoerzentralle", in the USA it was called "Service Interception", etc.).

The first steps in the area of radar installations were taken during the period between the two wars.

---

* A. Pali: Krieg im Aether, Deutscher Militaer Verlag, pp. 163, Berlin DDR, 1965.

**Ibid.

In 1904 C.H. Huelsmeyer (Germany) obtained a patent* which explained the use of electromagnetic waves for locating objects in space. The equipment was called "Telembiloscope" and represented radar by its conception. At that time, sufficiently strong sources of electromagnetic energy were not known. However, by 1935 intensive development work on radar had been started.

In 1935 physicist Robert Watson Watt (England) proposed a project to the Technical Subcommittee of the Research Committee for Air Defense to determine location of airplanes in space by sending electromagnetic impulses. The project was accepted and by 1938 a chain of five radar stations of the CH (Chain Station, Home Service) type were constructed and put into experimental use. These stations operated in a wavelength band 12 m. The stations were arranged 25 km apart and surveyed the air space over the mouth of the Thames. In August 1937 this chain was extended by the addition of another 15 stations which completed protection of the eastern and southeastern coast of England. The chain was put into operation for the first time in 1938 during the visit of British Prime Minister Chamberlain (sir Austin) to Munich. The second time the chain was activated during the German occupation of Czechoslovakia in November of the same year and its operation was continued up to the end of the Second World War.

At the same time intensive work was in progress to develop radar that could be installed on an airplane. A plane reconnaissance radar for surface targets, type ASV (<u>Airborne Surface and Surface Vessel</u>) was tested in maneuvers in September 1938. This equipment was installed in patrol airplanes already in 1939 and was operating at a wavelength of 1.5 m. It was used for detection of ships.

A radar for fighter planes, type AI (<u>Airborne Interception</u>), was demonstrated in the beginning of 1939. The British Airforce ordered 30 units with this equipment. On the day the war started there were four planes equipped with these units ready for operation and the rest was completed by the end of September 1939.

---

* German Patent DRP 165,546 class 75d 11/21/1905.

Using the aircraft Graf Zeppelin the Germans carried out radio- reconnaissance in the area of the North Sea (in the spring of 1939). They listened to and analyzed British radio transmissions to detect British radars. Their flights were detected by the British radar network. Eavesdropping was done using very sensitive receivers which, unfortunately for the Germans, did not cover all frequencies that were used by the British at that time. Thus the German operators could not record all transmissions and form a realistic picture of the British potential.

Germany was a leading nation in the area of the navigation equipment for aviation. Their system of guidance by directed radio-beams type "Lorentz" (named according to the manufacturer of the same name) was used by all larger European civilian airports after 1930. In fact, it was used by the British War Airforce.

System Lorentz was modified for future needs (in Germany) by Dr. Hans Plendl. The modified system referred to as X - Geraet (Equipment X) operated on frequency of 66 to 75 KHz. The system may be described as follows: Four radio-beams were used, one guiding and three crossing beams. The plane was to fly along the guiding beam and meet the first cross beam at about 30-50 km before reaching the target. This beam served as a warning. At this point, the plane was to assume the required altitude and speed. The plane was to meet the second cross beam at a point 20 km before the target. Here the navigator in the plane starts a special double chronometer in which the first hand starts moving. The last cross beam is met at a point 5 km before the target. The navigator presses a button which stops the first chronometer and starts the second which runs three times faster than the first. When the hand of the second chronometer reaches the hand of the first the contact activates the equipment for automatic release of the bombs. Because the second chronometer runs three times faster than the first and the first chronometer was in operation over 15 km, Automatic release of bombs takes place at a point 5 km from the last cross beam. An example of this from the early days of the war is illustrated in fig. 4.1.

The range of the system was about 300 km with the accuracy of several hundred meters.

Figure 4.1. Application of the X-Geraet navigation system to bombing of the city of Coventry on the night of 11/14/1940. A-B = 30 km, B-C = 15 km, C-target ≈ 5 km. Stars indicate positions of active interference installations of type "Bromid".

The system was thought through and was consistent with the German military principles which ignored the existence of the British anti-aircraft defense. Only in this way it is possible to explain the need to maintain a straight line flight on a given altitude and at a constant speed for the last 20 km before the target. These conditions are just ideal for the anti-aircraft artillery.

The Germans had also great successes in the area of radar equipment during the pre-war years. Already in 1936 they constructed the first radar for surveillance of air space (type "Frey") which had a range of about 80 km. It operated on the wavelength of 2 to 2.4 m. This radar was of high quality and was used, with minor modifications, until the end of the war. At the time they entered into the war with Great Britain, the Germans had eight active radar stations of type "Frey" (2 units Helgoland, 2 units Sylt, 2 units Wangerooga, 1 unit Borkum and 1 unit Nordeiney) which covered the German coast and the area over Holland and Denmark. The German industry had in development and production a few radar types: Seetakt - a ship version of "Frey", Wurzburg - sighting radar, Mamut and Wasserman - a reconnaissance radar and Lichtenstein - an aircraft radar.

Such a large number of high quality installations and systems along with the German confidence in their superiority and the well known concept of the Blitzkrieg have brought about a neglect of further development of electronic equipment and a reorientation of the experts to the other areas "important for the war".

4.2. DURING THE SECOND WORLD WAR

The opponents entered the war with a developed service for the electronic activites and countermeasures. All parties accelerated their development of new methods and equipment and stopped at nothing to acquire data about the electronic equipment of the enemy. They used methods of air reconnaissance, electronic air and ground reconnaissance information from agents, questioning of prisoners, examination of downed airplanes and their equipment and in special cases they undertook raiding actions to capture technical documents and vital parts of the equipment.

The electronic activities and countermeasures developed into a truly secret war which the Prime Minister of Great Britain, Winston Churchill, referred to as the "Magicians' war...".*

The efficiency of the Allied electronic activities and countermeasures is illustrated by a statement by Dr. Joseph Goebbels in a meeting with Hitler on 11/7/1943**: "It is a shame how the enemy is pulling our leg in aerial warfare. Every month they find a new method of attack and we need weeks and months to find successful countermeasures...".

Radio-equipment

On 6/4/1940 radio reconnaissance and goniometry of the German eavesdropping service "Mithoerzentralle" discovered an accumulation of the Franch forces south of the Somme and Aisne and before the of-

* Winston S. Churchill, Second World War, Vol. II, chapter XIX, Prosveta, Beograd.

**Alfred Price: Herrshaft ueber die Nacht Bertelsman Sachbuchverlag 1968.

fensive on the Aisne (on 6/9/1940). They also discovered French forces between the Somme and the Seine. The discoveries occured due to failure of the French forces to stop their radio communications before the German attack.

During their attack on the Soviet Union, the Germans obtained valuable information by radio eavesdropping until the Soviet units enforced a rigorous radio-discipline and secrecy.

In the war theater in Lybia, the British undertook (in November 1941) the first interference effort of German-Italian tank communications which operated on frequencies between 27 and 37.5 MHz. The interference was created using frequency modulated transmitters with 50 W of power. The transmitters were mounted on the "Wellington" type bomber planes. Although imperfect, they achieved great success. The main weakness of these efforts was lack of fighter support. Thus the interference planes were a relatively easy target for the Italian-German fighters.

In 1941, knowing the weaknesses of the British radio communications, the Germans organized (in the North African war operations) a powerful eavesdropping serivce which soon provided them with information about the distribution and organization of the Allied units. The breakthrough occured at the end of October 1942 when General Bernard Montgomery started the great offensive at El Alamain. In the course of 11 days the front was broken through and the German-Italian forces had to retreat in a hurry. During this event many German electronic installations were captured. The equipment was carefully disassembled and transferred to Farnborough (Great Britain) where it was reassembled and activated by a group headed by Dr. Robert Cockburn*. In this way the British learned thoroughly about the German capabilities and were able to develop proper countermeasures.

Interruptions of radio-communications by active interference had a very limited application during the Second World War. Partially,

*Alfred Price: Herrschaft uber die Nacht, Bertelsman Sachhichverlag, 1968.

this was because there was a danger of interfacing with friendly channels and partially because efficient interference required transmitters of very great power. Besides the prevailing conviction was that it is more useful to listen to the enemy's radio communications and thus learn about his intentions. Consequently, all the war parties gave great attention to directed beams and methods and techniques of coding.

Ground to air radio-communications used for guidance of planes were the object of active and sometimes clever interference during the whole war.

At the beginning of the war the British airmen used to make preflight adjustments of their radios while still on the ground, without uses of artificial antennas. On the other side of La Manche (English Channel) the Germans received these transmissions by their eavesdropping stations and used them as a valuable early warning for their anti-aircraft defense, because signals were received before any radar detection (while the airplanes were still on the ground).

On their side the British were eavesdropping on German command radiocommunications and guiding of planes. The short wave communications in the range of 3 to 6 MHz were interfered with from the ground using ionospheric reflections and powerful directed SW transmitters for radio-diffusion and BBC (General Post Office and Cable Wireless Company). As a defense against the German fighters during bombing of Germany, the British interfered with their communications in a very original way. They transmitted the noise of the plane motors on the German wavelength (system "Tinsel"). This system combined with a radar interference was used in December 1942 during bombing of Mannheim. On that occasion the British lost 9 airplanes or 3.3%.

The effectiveness of Allied aviation increased toward the last days of the war. The planes went deeper and deeper into the German territory, all the way to Berlin. Because German radars were paralyzed at that time due to effective active and passive countermeasures (see chapter on radar and navigation equipment), the air-ground communications which the Germans used to send their fighters to the endangered locations became very important. At that time the Germans

reorganized their anti-aircraft defense in such a way that the anti-aircraft artillery was used for altitudes of up to 5000 m, and fighter planes were used at higher altitudes. With this tactic they succeeded in downing 123 planes in three subsequent British attacks on Berlin (8/23; 8/31 and 9/3/1943). Such losses required a new system of countermeasures which was referred to as the Special Tinsel. The Germans used to lead their fighters to the bomber's route using strong radio stations in the range of 3 to 6 MHz. British interference system had great success on August 30, 1943 during their attack on the Moen-chenGladbach. The Germans used just one frequency which the British discovered and jammed. Seven minutes later the Germans changed the frequency only to have British discover it within 15 minutes and jam it again. During that attack British losses were only 3.8%.

As the consequence, the Germans changed to frequencies of 38 to 42 MHz.

Dr. Cockborn of Great Britain and his group build the "ABC-(Airborn Cigar)". This receiver consisted of a panoramic receiver with a cathode tube (7.5 cm in diameter) as an indicator and with a transmitter for interference. The equipment was mounted on a type "Lancaster" airplane and needed an additional member of the crew (which was uncomfortably positioned in the airplane - this gave equipment its name). As soon as the enemy transmitter started operating the panoramic receiver indicated its signal and frequency and the operator would adjust his transmitter for interference at that frequency. The operators were very familiar with the spoken German language. The interference was done using the so called "Corona" tactics i.e. by giving false commands in German language on the wavelength guiding German planes. This system achieved great success during attack of Kassel on 10/22 and 10/23 1943. British operators cut into the German radio network and created such a confusion that Germans did not down a single plane.

The first attack on Berlin was carried out on 11/19/1943 with 444 planes. Nine planes did not return, which was a small number for such a distance (600 km of flight above enemy territory).

As a countermeasure the Germans introduced a woman in the place of the officer directing the fighter planes, assuming that the British could not place a woman in the place of the operator on the plane. However, the British found in their auxiliary corps a sufficient number of women that also spoke excellent German. In continuation of these operations the British increased the power of their transmitting ABC equipment and the Corona tactics were replaced by transmission of Hitler's speeches, reciting of Goethe's work or citing of some, difficult to understand, German philosophers.

This countermeasure was parried by the Germans by transmitting orders simultaneously on three wavelengths. One of these was in the range of 3 to 6 MHz. Because of the reflections from the ionosphere these transmissions could be received in Great Britain. The British thus installed powerful transmitters for interference using antennas directed towards Germany.

For the transmission of information about flights of the Allied planes the Germans also used their military radio transmitter "Anne Marie" in such a way that the flight of the planes was signalled by the type of the transmitted music. Thus: waltz - indicated that the bombers are in the area of Munich; jazz - indicated that the bombers are in the area of Berlin; church music - indicated that the bombers are in the area of Muenster; carnival music - indicated that the bombers are in the area of Koeln, etc. The British noticed the regularity because at the departure of the bombers the German transmitter always played the march "Alte Kamaraden" (The Old Friends). They immediately built a strong transmitter named "Dartboard" using noise for interference.

After the end of 1943 German communications were completely paralyzed due to these countermeasures. For illustration here is a note from a German source*. On 12/16/1943 during a flight over Berlin the German communications were hindered by:

---

* Alfred Price: Herrschaft uber die Nacht, Bertelsman, Sachbuchverlag, 1969.

- SW ground-air communications were interfered with by ringing bells;
- SW air-air communications were hardly possible;
- VSW communications were interfered with by citations of Hitler's speeches
- reserve frequencies were immediately strongly interfered with;
- the military transmitter "Anne Marie" was interfered with by a steady tone.

In August 1944 because of the use of a 2 kW transmitter "Jostle" the German VSW communications were rendered completely useless.

Having no means of communications on other frequencies Germans started to use the Morse code signals as the last resort. This required training of pilots and radio operators of night fighters. As a countermeasure the British applied the system "Trommel Stoecke" i.e. used transmitters which, using German frequencies, transmitted Morse code signals without sense (randome combinations of signals).

The Germans urgently proceeded with work on a new communications system. By the beginning of 1945 they developed a technically refined system referred to as "Bernardine". The system consisted of a large, highly directed and rotating antenna which would radiate at an airplane and typed on a paper tape by a special "Bernardine" receiver. The Germans planned to equip all planes with this system by the Fall of 1945 but were interrupted by capitulation.

In their attempts to interfere with the Allied planes, the Germans were successful immediately before the landing in Normandy. They had 50 units of the interference equipment type "Karl 2" grouped in the vicinity of Dieppe at the Center for Interference. The Center was anihilated by the Allies before their landing.

A characteristic example of utilization of anomalies in propagation of electromagnetic waves for rado-reconnaissance was the determination of impact positions of German V_1 rockets directed at London. The German eavesdropping service in Norway cleverly used these anomalies and by receiving the VSW transmissions of the London Emergency Service and police they were able to obtain information about the

position of the impact of the projectile and thus to make aiming corrections.

All participants in the Second World War payed considerable attention to radio-eavesdropping and radio-goniometry. As an example, by 1942, Germany had an organized network of radiogoniometers on the whole Eastern Front and on the Mediterranean. By 1944 they divided the network into a part for surveillance of the surface and a part for surveillance of the space (each German company for radio-reconnaissance had within its organization 10 SW, VSW and USW goniometers and receivers).

The radio-eavesdropping service of the USA Navy (Service Interception) obtained quite accurate information about the Japanese intentions before their attack on Pearl Harbor in 1940. The American command did not have sufficient confidence in this information and did not undertake the corresponding countermeasures. Having learned from this experience they developed a broad organization for electronic reconnaissance and interference during the course of the war.

In 1944 the Allies had five eavesdropping centers in North Africa and in England.

The military literature states that the Allies were able (by the end of the war) to obtain or confirm 70% of their intelligence data by their good organization of the eavesdropping service.

An electronic war took place also during the People Liberation War in Yugoslavia between the People Liberation Army (PLA) and the armed forces of the enemy. This is confirmed by the following examples:

In summer of 1942 the radio-telegraph operators of the Headquarters learned that the units that attacked Sanski Most would be bombed and the units were promptly withdrawn. In another case radio-eavesdropping learned about movement of the enemy forces from Prijedor to Sanski Most. They were ambushed and suffered considerable losses.

In 1943 the PLA (People's Liberation Army) units attacked Koprivnica. During the course of the attack the enemy received and decoded

all radio-transmissions of the PLA units. After penetration into Koprivnica we found all radiograms of our officers decoded. Only due to the speed with which the defense of Koprivnica was penetrated were we able to avoid consequences that could have been serious.

The Second Brigade of the Seventh Banija Division(which was returning from Moslavina to Banija) maintained communications by radio. Suddenly, an enemy radio station cut into the radio network presenting itself as the radio station unit assigned to secure transmission of communications. In the last moment the legitimacy of this station became suspect and the brigade changed the direction of its movement.

Radar Installations

The use of radar countermeasures started at the beginning of the Second World War. On their southern and south_eastern coast the British had a chain of twenty radars of the CH type. The Germans learned about this chain from reports of their agents. Using airborne eavesdropping equipment they established positions and radiation patterns of the British radar stations. They thus found that the radiation pattern had some blind zones (because of a high placement of fixed antennas* and a low operating frequency -25 MHz) and they used those blind zones for their flights over Great Britain. The British then constructed a new installation type "CHL - Chain Station, Home Service, Low Cover**" with a low cover pattern which complemented the existing chain. As a countermeasure the Germans installed active eqipment for interference. The first equipment was installed in 1940 in the vicinity of Calais. Gradually a whole chain of radar interference was installed along the La Manche coast from Normandy to Ostende covering the frequency ranges of 20 - 30 MHz and 50 - 90 MHz. In 1941 this chain was supplemented by the interference equipment "Karl" which covered the frequency range of 200 MHz. These first installations for interference had broad ranges, had low power for the whole frequency range and were limited to short time operations.

*The antennas were installed on high iron towers and were directed to a given azimuth.
**The chain of observation stations of low cover.

Consequently, they did not completely disable the British radars but only muted the signals reflected from the targets.

The operation "Cerberus" is considered to be the greatest success of systems of active interference. It was used to bring out the German warships "Scharnhorst" and "Gneisenau" and the cruiser "Prinz Eugen" from the harbor Brest in Brittany through the English Channel to the mouth of the river Elba in Northern Sea.

The plan, decided upon on January 1, 1942, provided for: utilization (as much as possible) of bad weather season, leaving the Brest harbor in the evening of February 11th and passing through the English Channel in the early hours of the morning on February 12th, 1942; an escort of 20 airplanes type ME-109 during daylight and 15 planes type ME-110 at night. Furthermore, there was a Navy escort of 6 destroyers from Brest and 26 torpedo boats from Berk. The plan also required secrecy of the operation and interference with British radars so that their capabilities of surveillance would be reduced to zero.

According to the "Cerberus" plan, the jamming of British radars started already during the first week of January 1942. It was used intermittently in the morning hours to create an impression that it was being caused by anomalies in the propagation of electromagnetic waves. This scheme worked. British radar operators started getting used to these interferences and accepted them as a normal condition. The experts actually tried to reduce the sensitivity of radars to interference. However, because of rare inspections and insufficient information from France the impression remained that the interference was due to anomalies in wave propagation.

On the day the fleet left (February 11, 1942) the Germans leaked the news that all the high officers of the fleet from the Brest group were invited to a dinner in Paris. The fleet left Brest at 22:45 hours. The passage through the harbor gates was lucky for the Germans as the radar on a British reconnaissance plane, assigned to that area, broke down and the plane returned to its base. The group for interference paralyzed the whole radar network with exception of one new type of radar which was still in the experimental state. Its findings were neglected in the general confusion. Only between 10:00 h and 10:14 h,

during a period of interference interruption, did one of the radar stations record passing of the German fleet. At 11:30 h the order 825 was issued to a squadron of torpedo planes for attack. The attack took place only at 12:45 h because of delays in preparation of planes and arrival of an escort. At that time the German fleet was already in the vicinity of Dover. At that point there developed the phase of tactical events which had the well known epilog: The slightly damaged "Scharnhorst" and "Gneisenau" and the undamaged "Prinz Eugen" entered the mouth of the river Elba on the morning of February 13th, 1942.

In 1942 the Germans started detecting ground observation radars using airborne detectors combined with interference. At the mouth of the river Nile, close to Baltim, there was one of the most powerful Allied radar surveillance stations. For a while this station was used by Germans as an extraordinary radio beam which guided their bombers at night to an important landmark - the mouth of the river Nile. It took the British some time to figure out that the specific signals used for interference with this station always preceeded the bombing of the Suez Canal. This case also serves as a classical example of poor organization on both sides - poor interference (too much before the action) and poor undertaking of the countermeasure (any interference should be properly evaluated).

In the fall of 1939 the German anti-aircraft defense had 12 "Frey" type radar stations covering the air space above the German coast on the North Sea and the territory of Netherland and Denmark. On the morning of December 18, 1939 24 airplanes type Wellington were on the way to the area of Wilhelmshaven with the assignment to patrol and bomb German warships. A little after 12 h radar "Frey" on the isalnd Wangerooge discovered the bombers at a distance of 110 km. The head of the "Frey" station called in the fighter planes (16 Me-110 type planes and 34 Me-109 type planes) and led them to the British group. This turned into a complete success. The British group suffered great losses and only 9 planes returned home. This was also the first time radar was used for the guidance of planes.

A "Frey" radar located on the Cherbourg peninsula played the main

role in guiding German bombers (on July 23, 1940) to the destroyer "Delight" which was sunk 30 km south of Portland Bill.

The British learned about the existence of German radars from reports of their agents which was received by the British Navy attache in Oslo on 11/4/1939. In the British circles this report was referred to as the "Oslo Report" and contained much information about German secret weapons. Again, British agents reported (in July 1940) about the distribution and use of the "Frey" radars and attempts to determine their type were made by use of aerial photography. However, aerial cameras were poor at that time. Only after using improved aerial cameras on 11/22/1940 they discovered two parabolic antennas 6-7 m in diameter in the vicinity of the village Anderville. By that time their agents reported existence of a "Frey" radar in that area (and that two radars type "Wurzburg" were sent to Bulgaria and Rumania). Not until April 16, 1941 did the British succeed to take a low altitude photograph of a "Frey" radar. At the same time an eavesdropping station in southern England discovered its signals at 120 MHz. Tracking of "Freys" took about a year.

Induced by the success of the "Frey" radar the Germans started (in the Telefunken Laboratories) to manufacture a radar for AA needs. This radar was quite primitive with manual antenna movements and determination of direction by the maximum method. The first models were mounted on anti-aircraft reflectors using green lights and were located at Falkensee in the vicinity of Berlin and at Essen-Frintrop. Using this equipment the AA forces had much more success in downing the British planes. British pilots reported that Germans had mysterious green rays which do not lose an airplane once they find it. This equipment was further technically improved into the "Wurzburg A" to "Wurzburg C" with the designation FuMg-41. By March 1945 the Germans produced about 5000 units.

Approximately one month after discovering radar "Frey" the eavesdropping group 109 discovered signals on the frequency of 570 MHz. By May 8, 1941 a reconnaissance group discovered a reflector on Cherbourg peninsula which was directed at planes with great accuracy. This was the first data about the radar "Wurzburg" but was insufficient for

undertaking any countermeasures. In the meantime this radar caused great losses to British aviation.

From reports of their agents the British learned that the Germans placed a radar of this type in the region of Barneville (France) along the position of a "Frey" radar. Low flying aerial photography discovered existence of a parabolic antenna in that area. A parachute attack referred to as "Biting-Bising" was carried out with participation of 119 paratroopers (technical experts) and 12 airplanes. On February 27, 1942, within a period of half hour they sketched the radar equipment, dismantled the antenna, the receiver, the transmitter, the modulator, the synchronizer and the UF amplifier and carried them to a submarine. They did not have time to dismantle the indicator. This was one of the best organized commando actions during the Second World War.

Even all these data were not enough for the British to devise the countermeasures. Later in the October 1942 offensive at El Alamein in Northern Africa the British captured a completely operational "Wurzburg" radar which they reactivated and thoroughly examined.

In the meantime information about the "Frey" radar kept increasing and by the end of October locations of at least 27 installations were established. It is of interest that eavesdropping on radio communications between "Frey" stations and their anti-aircraft defense centers contributed considerably to the detection of their positions. Radio communication was carried out with short waves using very primitive codes. Following is an example of such a communication that took place in October 1941:* MFX = 114,011 = 14E = X = 254 = 36, which meant: MFX - designation of the "Frey" station; 114,011 - hour, minutes and seconds; 14E - number of the message; X - number of targets (X = one, Y = more, Z = many); 254 - azimuth in °; 36 - distance in km.

The data obtained from "Frey" radars proved sufficient for Dr. Cockburn and his coworkers to design equipment for interference (referred to as "Moonshine"). The equipment received the signals from "Frey"

*Alfred Price: Herrshaft ueber die Nacht, Bertelsman Sachbuchverlag 1968.

radars, amplified them, and retransmitted them. As a consequence, the "Frey" screen, showed many false targets. The first experiment, occurred on August 6, 1942. Six airplanes flew in the direction of the Cherbourg peninsula with their "Moonshine" equipment in operation. Because of the many false targets the Germans flew all their available fighter planes. Eleven days later "Moonshine" was used to disguise a real operation. A few planes, using "Moonshine" equipment went in the direction of the Thames while real attackers with fighter support went in the direction of Rouen. The Germans sent 144 planes to the imaginary group and half as many to the real group. Within the next months "Moonshine" was used 28 more times with variable results. The reason for this was the fact that each "Frey" used a different frequency and that the false signals were grouped too close together which did not appear like the real situation. Dr. Cockburn and his coworkers then designed a wide range equipment (type "Mandrel") for active interference with noise. This radio interference equipment operated in the frequency range of 118 to 128 MHz. In summer of 1942 this model was in regular production and by November 1942 the planes equipped with this model patrolled along the west German coast and thus paralyzed the "Frey" type radar network on this coast. The radars of the "Wurzburg" type were still uneffected.

On the basis of data from the captured "Wurzburg" equipment, the Harvard University experts in USA designed new airborne interference equipment, model "Carpet", which was used for the first time in September 1942 during an attack on Bremen. The losses were significantly reduced and were suffered mainly by the fighter planes.

In February 1942 (at the Leeuwarde airport in Holland) JU-88 with Yagi-antennas appeared which protruded from the body. This was the self-guiding airborne radar, model Lichtenstein manufactured by the Telefunken Company. It operated on a frequency of 490 MHz with a maximum range of 3 km and the minimum range of 200 m. This was excellent for that time. Again the losses of the Allied planes were disturbingly increasing. The reason for this was the fact that the frequency range and the power of the existing equipment for active interference were insufficient to block the "Lichtenstein" radar.

"Lichtenstein" equipment was carefully guarded by the Germans.

Only at the beginning of 1943 did the British succeed to obtain an undamaged unit from an airplane which was forced to land in England and the pilot forgot to activate the destruction detonators. The properties of this device were determined by its examination in laboratories and in flight. A very clever equipment ("Serate") de_ signed on the basis of these data were then designed as a counter_ measure. The equipment for countermeasure consisted of a receiver which utilized radiation from the radar "Lichtenstein" as a precise directing radio beam. A cathode tube was used as the indicator which showed a picture as illustrated in fig. 4.2.

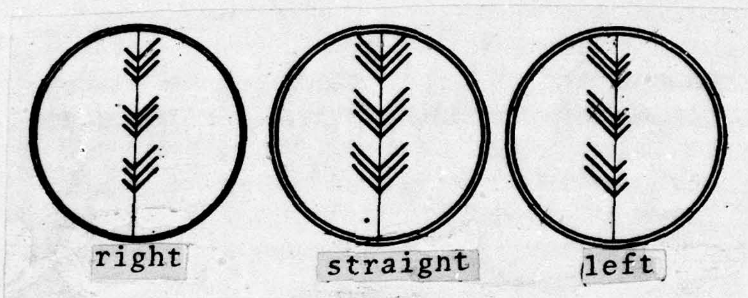


Figure 4.2. Observation of radiation from radar "Lichtenstein" on the "Serate" equipment.

When the impulses from both sides of the vertical time base were equal, the airplane with the "Serate" equipment was pointed to the air-plane with "Lichtenstein" equipment. The length of the pulse indicated the distance. The precision of the "Serate" equipment was so good that during the attack on the V_2 factory at Peenemunde on August 17/18, 1943 the British fighters downed five German Me-110 fighters using the "Serate" equipment for aiming.

At the same time the Allies introduced passive dipoles as a radar countermeasure. They had a great effect on the "Lichtenstein" radar. The planes equipped with this radar mistook the dipole clouds for real planes and wasted their time and ammunition on them.

The Germans were forced to change the radars on their night

fighters.
In October 1943 they replaced them with the model "Lichtenstein SN" which was capable of a fast change of frequency within a very broad range about the average frequency of 200 MHz. The British were surprised by both the wavelength (too large for an airborne radar) and by the speed of the changes. Losses of bombers due to night fighters increased rapidly and reached a maximum of 10-12%. This required an urgent implementation of efficient countermeasures. As an example, during the bombing of Nuremberg on 3/31/1944, 95(or 12%) of the 795 bombers that participated in this action were downed along with the 950 crew members.

At that time a new transmitting electronic tube type "Resnatron" was discovered in the USA. This tube enabled large power emissions in a very broad frequency range.

After 18 months of strenuous research efforts, new equipment for active interference (referred to as "Tuba") was constructed and was put in operation by June 1944. Its effect was such that the Germans were forced to change drastically their night fighter radar equipment.

Radar equipment called "Monica" designated as "Transm.-Receiver" was mounted in the tail of each of the Allied planes. This radar covered the space within an angle of 45° for a distance of up to 1000 m. Entry of an enemy plane into the covered space produced a sound signal whose frequency decreased as the distance increased.

In a "Halifax" plane downed on 3/2/1943 over Holland, the Germans found equipment marked "Transm-Receiver"and they determined its use. At the same time they found a receiver, model "Boozer" for "Wurzburg" radar signals which used a light signal for warning the pilot. The Germans were surprised by the British knowledge of their frequencies.

Using data from radar Monica the Germans built a radar receiver "Flensburg" which could detect and indicate the direction toward "Monica". Accidently the "Flensberg" equipment was also detecting the operation of the British equipment for verification (IFF). The Germans used this method until the middle of 1944 i.e. until the moment when a German night fighter, model JU-88, changed direction

and landed undamaged on British territory. The British learned about the equipment "Flensburg" and recognized the danger to the "Monica" and IFF installations. The installations "Monica" were immediately disassembled and use of IFF was reduced to a minimum.

A characteristic example of electronic war is also represented by the battle between the British airborne radars model ASV (Airborne Survey of Surface Vessels) for surveillance of the sea surface and German ships and submarines.

The first radar of the ASV type, using a wavelength in the range of 50 cm, appeared in the Summer of 1941. The British designated it as "Mark I". Its application was fatal for the German submarines (which had to surface during the night to charge their accumulators and for supplies). The German warship "Bismark" was sunk in May, 1941, by help of the ASV radar.

Using radar, the British cruisers "Sheffield" and "Suffolk" discovered the position of the ship, and the torpedo planes equipped with ASV-radars (launched from the aircraft carriers "Victorious" and "Ark Royal") torpedoed it on May 27, 1941. The "Bismark" sank as a consequence.

On the same day radar laboratory of the firm Telefunken received a captured example of an ASV model radar. They examined it and on that basis developed a sensitive receiver (Model "Metox") for radar signals. The receiver enabled an early discovery of reconnaissance planes equipped with ASV-radar _ much sooner than the plane could discover the submarine before it submerged.

In 1941, thanks to discovery of a strong magnetron, British developed an ASV - radar on the 10 cm wavelength. This 10 cm ASV radar (Mark VIII) was mounted on a large number of "Mosquito" planes. This increased German submarine losses and by 1943 two thirds of the losses were caused by this type of radar.

As a countermeasure the Germans introduced detector "Naxos". The Allied reacted immediately and replaced the 10 cm range ASV-radar with a 3 cm range ASV-radar. Since Germans were behind in microwave

technology they equipped their submarines with equipment for "underwater breathing" referred to as "Schnorckel". Only just before the end of the war did they introduce a detector equipment named "Mucke". This example shows the uncompromising aspects of the electronic war. A change of three generations of measures and countermeasures took place in a very short time and under very difficult conditions. During the use of the ASV type radar, the British Naval aviation sank 3.5 billion registered tons of German ships.

By the end of 1943 British intelligence learned that German submarines were using radar equipment of great range which could be operated even when the submarine is not completely surfaced. The USA Ministry of War promptly supplied a receiver for eavesdropping and analysis of signals, which was mounted on a patrol plane together with a special antenna. For a long time this search plane could not find any trace of German submarines. This mystery was resolved only after the war duing interrogation of the prisoners. They stated that the Germans did not use this submarine radar at all for fear that it would reveal their location to the Allied reconnaissance planes.

The Germans lost their radar battle because of lack of power generators in the centimeter wave range. It is an interesting fact that magnetrons with the range of 5 and 9 cm of small power (100 mW) were produced already in 1939 in the Telefunken laboratories. Within this firm there was a strong microwave laboratory which worked under Dr. Ilberg until 1942 and developed a microwave radio-relay equipment referred to as "Michael-Rudolf". On request of German authorities (assigned responsibility for development) this laboratory closed its operations and their experts were sent to other assignments. Presumably this was based on the belief that a military microwave technology was of no interest. Prof. Dr. Leo Brandt head of the Telefunken Company development at that time and head of the German radar development since 1945 attributes this failure to the confidence of the German military leaders who at that time had plenty of radar equipment of high quality. According to their war doctrine they considered any further development in the microwave area as unnecessary. History has shown these estimates to be unrealistic. Work in the microwave area was again permitted in 1943 but it was too late.

The first results of this work appeared just before the end of the war and had absolutely no effect on military operations.

Passive Radar Countermeasures

The use of thin metal strips (passive dipole reflectors) as a means of creating confusion in radar systems or to decrease their effectiveness was known by all warring parties already at the start of World War II.

Both the British and the Germans kept this discovery as a very important military secret because they were afraid that it would immediately be used by the enemy against their own radar installations. The British were afraid that in their new air raids against London the Germans would use passive reflectors, with catastrophic results for the British. The Germans, however, were afraid that their "Frey" and "Würzburg" radars would be made totally ineffective. Both sides worked urgently on finding a countermeasure. And both sides found this countermeasure - in the use of the "Doppler effect," i.e. distinguishing the airborne targets according to their speed.

The British called their dipole reflectors "Window"*, the Germans called them "Düppel," the Americans called them "Chaff"**, and the Japanese called them "Giman Shi."*** The modern literature generally uses the word "Chaff."

British Prime Minister W. Churchill approved the use of "Window" strips on 23 June 1942, but their production did not start until the end of 1942. The strips were 30 cm long and 1.5 cm wide, and were made out of black colored aluminum foil which would render them invisible in reflector light. A packet of 1,000 strips created the

---

* - window

** - noodles

*** - attenuating paper

same reflected signal as a bomber. The cost of a packet was four pence (0.5 dinars). By the middle of 1943 the production of the strips was sufficient to begin with their use.

The "Window" strips were used for the first time during a night attack on Hamburg, a German industrial and marine center. The anti-aircraft defense of the city consisted of 54 anti-aircraft gun batteries of medium caliber, 22 reflector batteries, and three "listening-in" (tapping) batteries, as well as 6 fighter plane airports. The plan for the air raid was carefully prepared. During the raid which lasted 45 minutes there participated 791 bombers; they delivered 10,000 tons of bombs. The plan of the attack required precise takeoff and flying within half minute intervals. Every minute during the departure and the return each bomber dropped a packet of strips at the geographical latitude 8^{o} to 9^{o} 30' East.

The effect of this countermeasure was extraordinary. Operators of the German radar stations were surprised and confused because simultaneously with reflections actually from the planes their radar screens also showed false echoes. At first, there were not too many of the latter, but they rapidly multiplied so that the screen was literally covered by signals. In this accumulation of signals, the true targets could not be discerned. Jamming signals remained present on radar screens throughout the duration of the attack, whereupon they slowly disappeared. The next day the Germans found a great number of tinfoil strips in the vicinity of Hamburg along the route of the bombers. According to German records, the "Würzburg" radar was completely paralyzed and the planes equipped with the "Lichtenstein" radar attacked imaginary targets. Of the 791 bombers which participated in the attack nine were downed by the fighters and three by anti-aircraft artillery. The British lost in this attack a total of 12 bombers (1.5%). The 92,000 packets of "Window"

strips used during this action resulted in a reduction of losses and thus saved the difference between usual losses of 6% and the 1.5% in this case, which represents, 36 planes with their crews.

The Allies immediately recognized the great usefulness of the "Window" strips. Each bomber flying over Germany carried a packet of strips sufficient to simulate 700 bombers. During the intensive bombing of Germany the Allies dropped each month approximately 20 billion "Window" strips. For this purpose, some 3/4 of the wartime production of aluminum was used for this purpose, resulting in a real shortage of aluminum at the end of the war.

In order to wear out German fighter planes and their anti-aircraft artillery, the Allies used to send planes over Germany which would simulate massive air attacks during those nights that they did not carry out air raid, by dropping "Window" strips. The routes of these flights generally did not coincide with the usual routes, and these strips were dropped over lengths greater than 500 km.

Passive interference of this type greatly reduced the effectiveness of anti-aircraft artillery. Instead of 800 shells fired which have until then been required on the average to down one Allied bomber, some 3,000 shells fired were now required.

The Germans reacted very quickly to the use of "Window" strips. During their attack on Bari (2 December 1943) they totally surprised the Allies by using their own strips for the first time.

In December 1943, the Germans introduced against "Window" strips the radar "Würzburg", which makes use of "Doppler effect" to separate (distinguish) the echo from the strip from that from the airplane; this means that the strips rapidly lost in speed, while the speed of the airplane remained constant. Ths shortcoming of this device was that it recorded only relative speeds higher than 20 km/hr, in

the direction of the device, whereas it did not react to lateral flight. Not satisfied with this solution, the Germans complement the "Würzburg" radar by the "Nürnberg" installation, in which the separation (distinguishing) of false from true echoes was based on on that the signal from the true target - due to the turning of the propeller - is amplitude-modulated, whereas the signal from the cloud of strips contained no modulation components whatsoever. The operator of the "Nürnberg" installation had special hearing aids and he could by means of the characteristic tone (due to modulation) select the true from the false targets. The effectiveness of this operation depended on the degree of training of the operator.

The Japanese used their passive dipole reflectors "Giman - shi" (an invention by the captain of corvette Hajime Sudoa) for the first time during their night attack on Guadalcanal, in May 1943. Their strips were 75 cm long and 3 mm wide. They were packed into packets containing 20 pieces each. During their flight toward the target the airplanes dropped one packet every 5 seconds.

The application of "Window" strips against Japanese radars on the Pacific was almost impossible, inasmuch as they operated on a very wide frequency region (from 70 to 200 MHz). For this reason, the Americans used aluminum foil strips 100 to 150 m long and 10-20 mm wide and suspended onto small parachutes called "Rope." Every B-29 bomber carried approximately 300kg of such strips, at the expense of bomb cargo reduction.

For the protection of their airplanes and to decrease the great effectiveness of German anti-aircraft artillery the Americans at night also used nets drawn by the airplanes (Fig. 4.3). Metallic nets were targets with a high reflection intensity, and the radar installations of anti-aircraft defense aimed their guns at them.

The German Navy used passive reflectors as a means of radar deception. Its submarine fleet used passive countermeasures "Aphfrodite" and "Thetis" to deceive the British reconnaissance planes equipped with ASV-type radars. "Aphfrodite" were small

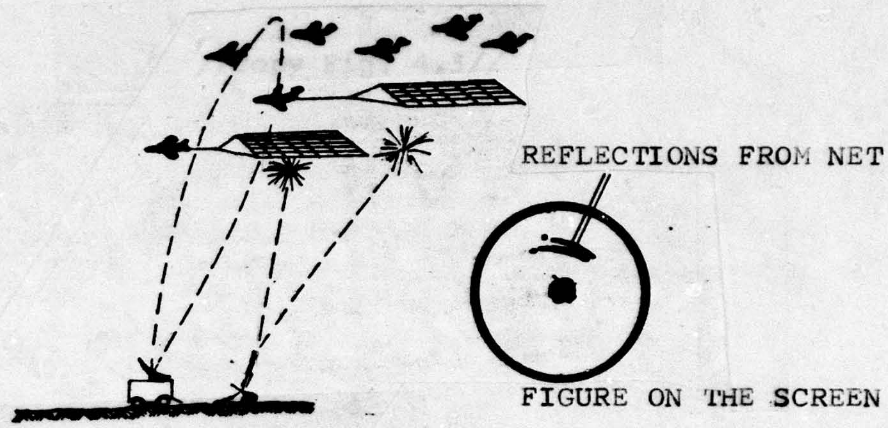


Figure 4.3.

Metallic net as artificial target.

balloons filled with hydrogen at a height of 20 m. On the wire which held the balloon, at the distance of 9 m, were fastened three dipoles 4 m in length, which formed a radar echo the size of the submarine. "Thetis" were angular passive reflectors positioned on small barges. This deception was quite effective. Known are even some cases when the German submarine torpedoes the American destroyer which followed the passive reflector.

During World War II both warring parties made use of the wide possibilities of radar masking of salient ground targets. The masking measures used by the Germans decreased significantly the effectiveness of Allied bombing by means of radar bomber target sights. At the same time, by changing the radar picture of the

terrain flown over they introduced an element of uncertainty into the operation of the airplane's navigator.

During the air raid on Berlin the Allied pilots availed themselves of the surrounding lakes for their orientation, inasmuch as these lakes have a specific shape. The Germans had planned to cover up these lakes and other orientation objects by variously oriented semiwave dipoles. However, this plan was never effected, since to cover the terrain by passive dipoles 3 and 10 cm of the wave range in various orientations a tremendous amount of the dipoles was necessary. Another attempt consisted in setting up large angular passive reflectors onto the lakes, at distances between them which corresponded to the width of the radar beam. By these reflectors the goal - masking of the lakes - was achieved, but their cost was very high and it was hard to secure them firmly. A further attempt was the use of angular reflectors made of two metal plates, at right angle, which formed two sides, while the water surface on which the reflector floated, being fastened onto a wooden coffinlike barge, formed the third side (Fig. 4.4).

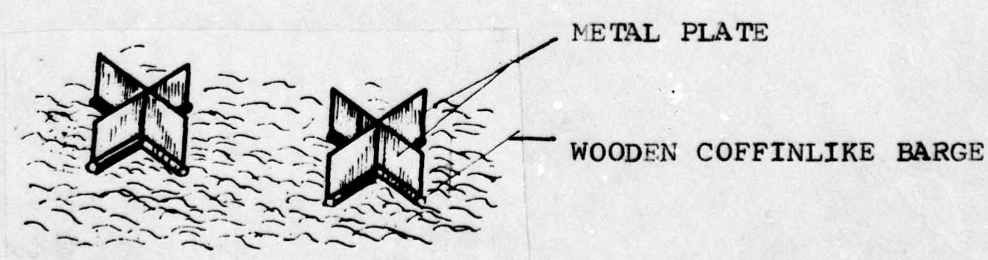


Figure 4.4.

Angular floating reflector.

The reflectors were 1x1m and 2x2 m in size. The Germans attained their goal: The masked surfaces of the lakes could not be distinguished from the surroundings under any observation angle whatsoever. The

effectiveness of Allied attacks whereby radar orientation was being used, decreased significantly. What's more, the Germans "constructed" on the surface of the lakes false targets by using reflectors of this same type. Thus, during a single bombing raid approximately 100 four-engine planes dropped their cargo — onto the lake.

Depending on the need, the Germans used reflectors of various dimensions. Thus, for instance, in the Berlin area they constructed false airports by means of angular reflectors 10x10 m in size. The reflecting surfaces were made of a finely knit net, due to lesser resistance to wind. With the use of 50 reflectors a large factory is simulated; on the screens of airplane radars it gave even better echoes than the actual factory.

Toward the end of the war, the Germans used angular reflectors to simulate Kistrin Castle at a distance of some 80 km from the actual position of the castle. Electrical power stations were protected in a similar way (such as Petlic near Stettin), as well as other important objects.

For the protection of expressly vital objects against bombing by means of radar installations of the H2S and H2X type, the Germans in 1944 developed special ground active jammers, which utilized direct or indirect illumination of the bomber's radar installation. In case of indirect illumination by the interfering signal, the object protected was illuminated and the thus reflected signal from the object was used as active jamming signal. One had to take care that the level of the reflected signal was sufficiently high so that the recognition of the guarded object on the radar picture was not possible.

For the protection of their territory by such a method the Germans placed approximately 300,000 transmitters at 100W; through them they masked not only the vital objects, but also all the more salient ones such which the Allies could use as orientation points for their bombing missions.

Electronic countermeasures played an important role also during Allied landings. Active jamming was used for the first time for this purpose during the landing in Salerno (Italy) in September 1943. At that time, 50 radar installations jammers installed on landing ships successfully jammed the coastal radar installations. In a similar way, the infantry units were protected during their landing at Anzio in January 1944 and during the taking of Elba island in June of the same year; in that case, the jammers were mounted on torpedo boats.

As the war proceeded, the application of active and passive electronic countermeasures became more and more massive; they were getting to be used also to create genuine electronic diversions of large sizes so as to deceive the enemy. A classic example of such an electronic diversion is the Allied operation "Fortitude" (during the night of 5/6 June 1944) which directly preceded the Allied landing (operation "Overlord") in Normandy. Some 11,000 airplanes, 4,000 ships of all kinds and 1,703,000 persons, with 365,000 vehicles participated in it. It is understandable that the preparation of such a vast operation could not be kept secret. For this reason it was necessary to keep Germans in the dark till the last moment regarding the time and place of landing. Germans knew that the northwestern coast of France is very suitable for a landing, which is why they concentrated here a great number of radar installations

for the observation of the airspace and the sea surface and the installations for the guidance of anti-aircraft guns and coastal artillery guns. On the belt along the coast they set up some 12 types of various radar installations at distances of 2 and 2.5 km between them. Thus there were 47 radar stations between the Diepe port and Cotentin Peninsula, each of which was made up of a "Frey" type search radar of wide range and a "Würzburg" type sight radar. The radars were able to operate within a relatively wide frequency range (100 MHz for "Frey" radars, 150 MHz range for "Würzburg" radars). This technical capability the Germans made use of by displacing the operating frequencies of the neighboring radars by 8 MHz. Each knocked-out (destroyed, jammed) radar could be immediately replaced. Availing themselves of the operation "Cerberus" experiences, the Germans also mounted a large number of jammers on the northwestern coast of France. Such an electronic situation was extremely unfavorable to the Allies and required massive application of thereto known electronic countermeasures.

Already in November 1943 there was developed a plan of electronic countermeasures for the Allied air forces, navies, and armies for the sake of disorganizing German electronics.

In the preparatory period the Allies mounted some 700 transmitters for jamming on airplanes, ships, and vehicles; they systematically uncovered positions of German radar stations and jamming stations; the found suitable passive dipole reflectors against "Frey" radars (put together in the form of a haromica, due to high length, since the "Frey" radar had a large wavelength) and they prepared adequate amounts of new and "Window" passive reflectors for dropping from airplanes by means of cannon shells and rockets.

The invasion started with intensive air attack on the uncovered radar stations and electronic centers on 5 July 1944. In this attack some 60% of German radar installations and jamming stations were destroyed. In order to disable the remaining radar installations and to deceived the Germans as to the landing place, the following measures were undertaken during the night prior to the invasion:

1. By continuous alternate flights by British and American airplanes and the concomitant dropping of passive dipole reflectors, massive attack toward Flanders was simulated. German fighter planes were baited onto false targets. Since their air-ground radio communications were intensely jammed, they were excluded from operative usefulness until they landed.

2. A "fleet" composed of the following sailed out of Newhaven:

a) 4 little ships equipped with the previously mentioned "Moonshine" installation. They were pulling a raft onto which was tied a "Filbert" balloon with a passive reflector 3 m in diameter inside. The reflector created an echo on radar screens equivalent to the echo from a ship having 10,000 gross tons.

b) 14 small barks equipped with "Armada" balloons, again pulling behind them a raft and a "Filbert" balloon.

In the middle of the Channel, the "fleet" divided into two directions. One ship and 8 little barks ("Glimmer" group) went in the direction of Bologna, along the "support" of the 218th air group, which simulated a powerful air-fleet formation. The second group "Taxable" was composed of 3 ships and 6 little barks aimed in the direction of Cap d'Antifiere, or corresponding to the "support" of the 617th air group. The "fleets" floated up to the Flanders coast, some 10 km before reaching it sunk the balloons and through strong loudspeakers emitted the characteristic anchoring sounds of a large

number of large ships.

3. 29 airplanes of the "stirling" and "halifax" type simulated the airborne landing in the Cannes and Cap d'Antifiere area (operation "Titanic"). The effect was amplified by the use of "Monshine" installations and the "Window" strips. At the landing site parachutes with puppets - special bombs in the form of frogs - were dropped out, which with their explosions simulated intensive battle, as well as a few parachutists whose job it was to create as much noise as possible.

At the same time that the false landing was performed, the actual landing was also performed - with 1,069 airplanes in the vicinity of Normandy.

4. Simultaneously with the deception, in the area of actual invasion 20 airplanes with jammers shadowed the screens of German radar stations.

The actual invasion commenced on 6 July in the early morning hours. Thanks to vast deceptions, the Germans arrived at the site of the invasion from 18 to 48 hours late.

The Allied losses in this operation were minimal. Out of 105 jammer airplanes, only 3 have been downed. Neither German Air Force nor their coastal artillery hindered the infantry fleet during their approaching. Out of 2127 ships which participated in the first attack, only six were sunk.

The electronic diversion experiences obtained during the operation "Fortitude" were used also during the landing in southern France.

In this action, more than 250 active jammers was used, mounted on 130 airplanes and 120 ships of all kinds. Like during the Normandy invasion, besides the main direction two landing directions were also simulated using a flotilla with passive reflectors and aviation support, with active jammers and passive jamming by dropping of dipole strips.

Immediately prior to the invasion, there was an air attack (in which 500 airplanes participated), whereby all German radar setups were destroyed.

Navigational Systems

An inflamed and enraged battle raged between the British and the Germans also in the area of the application of jamming of radio navigational systems for the guidance of airplanes throughout the duration of World War II.

Due to successful bombing of Britain, especially London, but because of the insurmountable poor visibility in this region which made visual navigation difficult, the Germans installed a large number of navigational radio stations aimed at London. Upon entering the war. the Germans had at their disposal the "X Gerät" system, in actuality modified by the "Lorenz" system (see p. 30 of copy). The system "X Gerät" did not make it, as it was too complicated to be used and was also a suitable target for anti-aircraft artillery. Because of this, the firm Telefunken produced the system "Knickebein", which used frequencies of 30, 31.5, and 33.3 MHz and airplane installations of the "Lorenz" system. With antennas 100 m in diameter the system attained a range of 450km at an altitude of 6,000 m. The width of the beam was 0.33°. The system consisted of two narrow beams, which were crossed above the target (Fig. 4.5). The transmitters were intersynchronized, with one emitting points and the other dashes. At the site of the crossing of the beams the points filled in the void between the dashes and the listener with earphones obtained a constant tone. The radio path along which a constant tone could be obtained was very narrow, and allowed an error in target determination of ± 800 m.

Toward the end of 1939, the Germans had set up three Knickebein stations (Kleve near the Dutch border, Stolberg on the western shore of Schleswig-Holstein, and Lörach, on the border between Germany, France, and Switzerland).

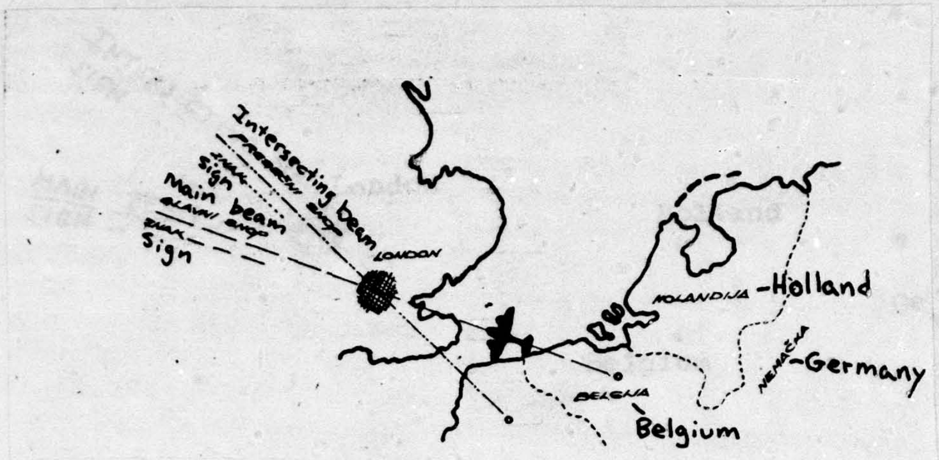


Figure 4.5.

German navigational system "Knickebein".

British scientists already in 1939 warned regarding the presence of German electromagnetic waves (physicist Dr. R.V. Jones).

In the known agency reporter "Osloreport" data have been found on the following two stations:

"Knickebein" by Bredstadt	54° 39' 8° 57'
"Knickebein" by Kleven	51°47'5" 6° 6'

The British did not know frequencies of individual beams. Out of three frequencies (30, 31.5, 33.3 MHz), the Germans always used two different ones.

On a downed "Heinkel 111" airplane, special installations were found, together with a note by the pilot, stating "Knickebein" 31.5. Likewise, on 20 June 1941, in another downed airplane the German

navigator forgot to destroy the installations and the noted data on the direction and the frequencies.

On 21 June 1941, Dr. Jones knew all the necessary data regarding several German "Knickebein" stations. That same day, at a session of the British Government, "Group 80" was formed, headed by Lt/Col B. Addison and Dr. Robert Cockburn, whose job was to find ways to disable German navigational systems. Diathermal medical apparatus was used first, which with their radiation created sufficient noise for the protection of individual cities (the countermeasure called "Headache"). From 7 September to 13 November 1940, the Germans sent 160 bombers for raids on Britain every night. This forced the British to look for some more effective means of jamming. They constructed transmitters called "Aspirin", which at "Knickebein" frequencies emitted points and dashes. Due to the additional signals, the German receivers did not obtain a constant tone, hence the plane prolonged its flight. In a later version the "Aspirin" transmitters were synchronized with German beam which they replaced and were aimed in such a way that the crossing occurred sooner and above non-important territory. The crews of German airplanes suspected that something was not in order with their beams. However, supposedly, during the first two months none had the courage to tell Göring about the lack of success of this system, on the contrary the German Air Force even received special comments as to the infallibility of the system and sanctions which shall be undertaken against anyone who doubts in it. Because of this, and also because of poor training of German pilots in classical celestial navigation, the British were able to deceived them for over two months, and during this same period they deterred from the proposed targets more than four fifths of German

bombs, which represented a success equal to an important victory.

For the return of their airplanes, the Germans had some 80 aimed radio phares; they constanly used 12 of them, keeping the rest in reserve. Which 12 will be used was for the British a secret until the last moment. For this reason the British constructed transmitters - aimed radio phares - with variable frequency "Masking Beacon — Meacon", with which they deflected German return radio directions. The first such device was installed on 24 July 1940; by 10 August there were already 6, and by 18 August there were 9 of them. By October 1940, "Group 80" had in its composition 20 officers, 200 soldiers, 15 "Aspirin", and 12 "Meacon" positions.

The "Knickebein" system ceased to be useful for the Germans. For this reason they changed over to using a modified "X Gerät" system (see Fig. 4.1). The alteration with respect to the original "X Gerät" system with which the Germans entered the war consisted in the transition to a higher frequency (74 MHz). Germans assumed that the British do not have transmitters at this frequency range and, likewise, that they are not familiar with the technology of this reagion. This system was used for the first time during the bombing of Birmingham on 13 August 1940. At this time the newly constructed factory for fighter planes was completely destroyed. Availing themselves of the expertise learned by uncovering the earlier systems, the British already in August 1940 discovered the guiding frequencies. In mid-September 1941 they were familiar with all the parameters of the German system. With respect to that they did not have a corresponding transmitter, they modified the radar transmitter of the system CH and called it "Bromide." In the meantime, the Germans bombed Coventry and destroyed its entire

industry, which was a heavy blow to the British (dropped were 56 tons of incendiary bombs, 394 tons of demolition bombs, and 127 parachute mines). Until mid-January 1941, the British already made so many "Bromide" jammers that the jamming by the German system was was ineffective. And in March 1941, the Germans stopped using this system.

The Germans had already toward the end of 1940 changedover to using the "Y-Gerät"* developed by the Telefunken firm (director Dr. Hans Plendl, constructor "X-Gerät"). This system had only one directed radio beam, along which 180 pulses per minute were emitted. On the airplane was placed an automatic device which determined the direction and responded to the pulses. The ground installation received these pulses, calculated the distance, and the determined instant sent the pulse for ejection of the bomb. This system was first used for airplanes of the H-111 type of group K.G 26, with ground transmitters at Poix, Cherbourg, and Cassel. The British already in February 1941 activated a jammer of the "Domino" type, which received the signals from German airplanes and which by a powerful transmitter emitted the signal for automatic ejection of the bomb. To avoid this jamming, the Germans on 9 May 1941 changed the frequency of the "Y-Gerät", however two nights later the British were already jamming them successfully. The effectiveness of the jamming by the "Domino" installation illustrates also the fact that out of 89 flights guided by the "Y-Gerät" from 1 to 15 March 1941, only in 18 cases were there obtained accurate data regarding the instant the bomb was dropped.

Dr. Cockburn, the British director of electronic countermeasures,

*"Y" device (installation).

declared that it was a very simple thing to disable the "Y-Gerät" since the Germans totally automitized it. The automatic installations on German airplanes were not capable of distinguishing the true from the false signals.

Due to their lack of success with the electronic system, the Germans started to use "target illuminator." This were airplanes equipped with all the navigational devices known to that time and with rank navigators. Their job was to drop small incendiary bombs for the sake of causing fires at predetermined objects to be attacked, so that the bomber groups which followed them could most easily discern them. As soon as they implemented this system, the British started to incite intensive fires at the sites of false targets; as a result of this, up to 95% of German bombs was then dropped onto these false targets. The Germans saw the cunningness of the British and the system changed in such a way that besides the incendiary bombs they also dropped true bombs. The British counteracted by that besides the fire caused by the German bombs they produced also another fire at opposite direction from the designated target. This procedure caused a greated dispersion of German bombs, with only about one half of them falling onto the true target.

In the application of electronic navigational means the Germans made some fundamental mistakes:

1) their radio navigation stations were placed in such a way that they were within the zone which could easily be controlled by the British listening-in stations;

2) they frequently experimented with new methods. They decreased the range, but this did not suffice not to be listened-in by the British listening-in stations;

3) they practiced the emission of their radio navigational equipment already during the first afternoon hours of the same day that the night attack was planned;

4) there systems were too pedantic, complicated, and for the most part automatized. Because of this they precluded from the training of the navigators and the pilots the conventional methods of navigation. An airplane with such pilots was generally lost, as soon as the guidance system failed.

Each of these factors contributed that The British obtained extremely important data and that they knew ahead of time what to expect. They had enough time, sometimes even several hours, to undertake the corresponding protective measures.

After the war, the German general Martini, director of this area of research, stated that he did not comprehend that the started a "high-frequency war" and that he underestimated British Intelligence Service and the organization of electronic countermeasures.

In a similar way the Germans also conducted their war against British systems for electronic navigation.

Professor Lindeman was commissioned by W. Churchill and in September 1941 made an analysis of the effectiveness of British bombing of Germany. He ascertained that the effectiveness of classical bombing technique is minimal, i.e. that only 1/3 of the dropped bombs fell within a diameter of 8 km around the target.

Already in 1938, the British scientist R. I. Dippy proposed a hyperbolic navigation system called "GEE." This system was perfected and in July 1941 was tested on an airplane flying above the North Sea. Two airplanes are used for the bombing of the Ruhr region on 11 August 1941. The following night one of the airplanes did not return from the attack on Hannover. In this case, a great in-principle error

was committed, i.e. the testing of a new system was done over unfriendly territory. The British were afraid that because of this the Germans became familiar with the "GEE" system, so they undertook great measures of caution. The designation of the system was changed (from "GEE" to "J"), the shape of the airborne and the ground installation was changed, so that it was similar to the CH radar, serial tables of airborne installations carried numbers R 3000 ..., which were the radar numbers. From airborne installations all identifying information was removed. The airborne installation received the designation TR 1335, which meant that one has to do with a prime receiver. For the sake of camouflage they installed three powerful ground directional "Lorenz" transmitters, and on the airplane they installed additional installations, and they trained the crew in their use.

At the start of 1941, some 30% of the bombers were equipped with the "GEE" system. The British estimated that the Germans had not discovered that system as of that time and that they will be able to use it approximately 3 months, i.e. that within that time the Germans shall have found effective countermeasures.

The "GEE" system was used for the first time for massive bombing of Germany on 8 March 1942. Months passed by and the system remained unjammed. During the first month of use 20 airplanes equipped with "GEE" installations were lost. The inability on the part of the Germans to detect this system was such that the crews of British airplanes called the installation "goon box", or idiot box.

The hyperbolic navigation "GEE" radio system is at the frequency range between 20 and 85 MHz. Figure 4.6 shows the principle of this system.

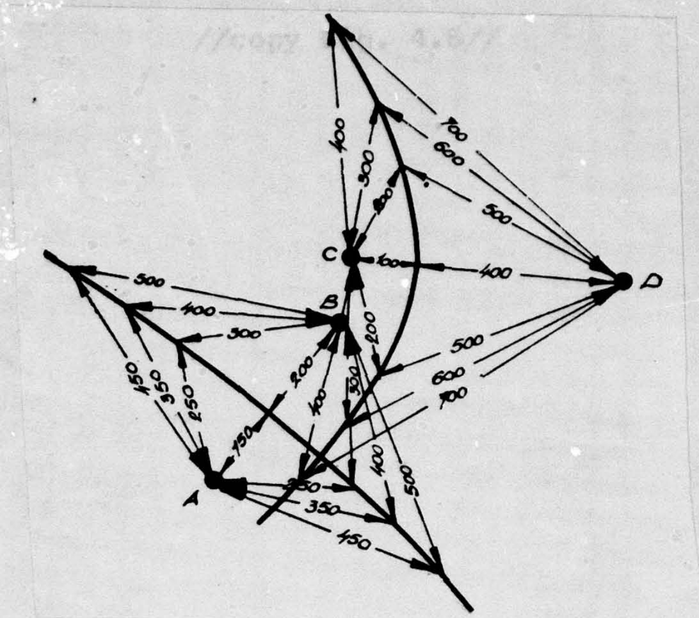


Figure 4.6.

Hyperbolic navigation principle of the "GEE" system.

Basically, the "GEE system consists of two very powerful (about 350 kW) transmitters (A and B, C and D). The distance of the transmitter in the pair is the base; it was between 100 and 125 km. With the help of its receiver installation the airplane measured the distance to individual transmitters. Since the distance line, or the distance difference, respectively, is similar to a spherical hyperbola, the intersect of this line with a similar or a measured line for the other transmitter pair gives the momentary position of the airplane. Since spherical hyperbolas are not suitable for representation on geographic maps, the lines of the same distance are represented by conventional hyperbolas with a rather good accuracy. Maps for "GEE" navigation were prepared and the only thing the navigator on the airplane had to do was to determine the route hyperbolas and the hyperbola intersects in order to be able to bomb the target.

The "GEE" system was essentially known to the Germans, inasmuch as the Telefunken firm already in 1939 proposed a similar system, however Hitler stopped its development. The Germans captured the first "GEE" receiver when it fell into the sea (on 29 March 1942) at Wilhelmshafev in case of a British airplane which was equipped with the "GEE" installation. The crew activated the detonators on the installation, but the sea extinguished them. The first tests met with no success, since the director of the investigation, Colonel engineer Schwenke falsely assumed that the British use a system similar to the "Knickebein" system. Only after five months of preparations have provisional jammers been set up in the vicinity of airborne objects, and the long-awaited jamming of the "GEE" system did not begin until 4 August 1942. Later the provisional jammers were replaced by the powerful jammers called "Heinrich." One of them was installed on the top of Eiffel tower in Paris. In October 1942 so many jamming installations were already operating that the useful range of the "GEE" system was decreased from 400-600 km to approximately 160 km, which was not sufficient for the purposes of bombing of Germany. Nevertheless, the system was not cut out entirely; the Allies used is till the end of the war, but only as a navigational system to help airplanes return after the completed mission (Fig. 4.7).

Because of Germant jamming of the "GEE" system the British developed a navigational system called "Oboe" and started using it in September 1942. The system consisted of two radar search lights (A and B) called "cat" and "mouse." During the onslaught of the airplane, the distances between radar search lights were carefully calculated on the basis of the geographical maps; the routes of the airplane and the targets were likewise carefully calculated. After the attack the airplane flew at the same distance from search light B (flight by

circular path) and dropped the bombs at a specific distance from search light A (triangle: airplane, A and B) or after a certain predetermined time of flight along the circular path after the intersection point (Fig. 4.8). The data regarding the distance from search light A and B the airplane obtained by means of the "question-answer" method (airplane by the coded question pulse, and the ground installation also by the coded answer code).

Installation for "Oboe" navigation were mounted on the airplane "mosquito", which during night-time bombing raids flew as the illuminator of the target in front of the bomber formation. In later operations of the 9th Army Air Corps of the USA, the bombing raids were done also in daytime, however only the leader of the "Oboe" formation was equipped with "Oboe" installations. The shortcoming of this system consisted in that one pair of "Oboe"

Figure 4.7.

Cover of the "GEE" system as of 1 November 1945 for flight altitude of 750 m with southeastern transmitter pairs.

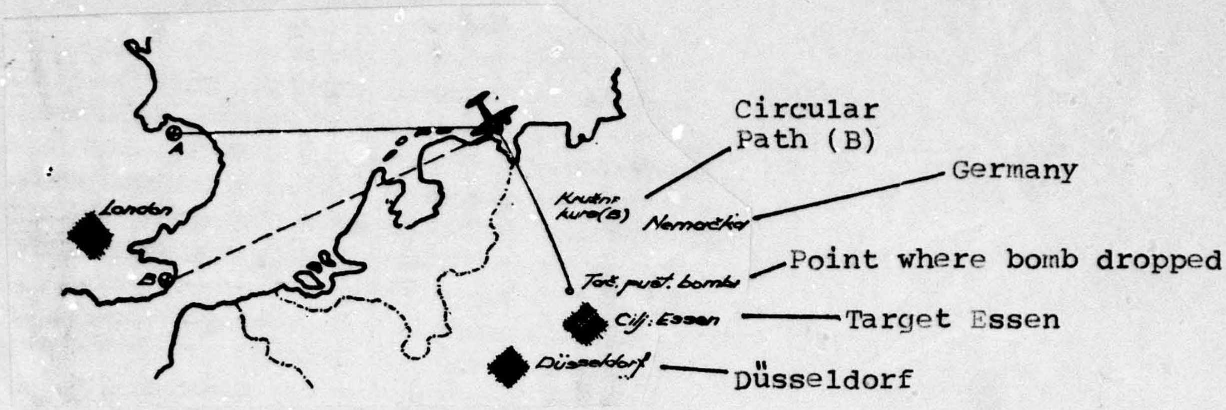


Figure 4.8.

Navigational system "Oboe".

transmitters was necessary for one guidance. With increased bombing intensification of Germany the need for "Oboe" guidance centers increased. Thus in March 1944 the Allies at the territory of Great Britain had already activated 44 centers for "Oboe" navigation.

The Germans for a long time did not know of the existence of the "Oboe" system. Thus, after the terrible bombing (on 5 March 1943) and destruction of Krupp factories in Essen, Hitler called together his staff and inquired about British technical possibilities and their navigational precision. Namely, the "Oboe" system provided a precision of 90%, i.e. 90% of the bombs fell on the target. Göring claimed that the British are getting such a success with a navigational system which is similar to their "Y-Gerät." Hitler made an experiment* of guiding with the "Y-Gerät" onto the target in an uninhabited part of Bavaria. Within a distance span of approximately 360 km, about

---

*Alfred Price: Herrschaft über Nacht /Dominion over the Night/, Bertelsman Sachbuchverlag, 1968. g.

50% of the bombs dropped fell around the target 900 m in diameter. This proved that the British use some other system.

In the meantime, the Germans attempted to simulate light bombs for "target notation" at another safe site. They had no success with this, since they did not obtain the same red color given out by the British light bomb.

Only on 7 January 1944 did the Germans down an airplane "mosquito" near Kleven, equipped with the "Oboe" system. Very quickly they recognized the system and within 3 days made a plan for a network of 80 jammers in the frequency range from 220 to 250 MHz. They called them "Anti Bummerung Gerät" ("Anti-Bang Installation"). The effectiveness of British bombing dropped from 90% to 20%. The British noticed this right away, and moreover, sent the Germans a wireless message on the "Oboe" frequency, "You are a Schweinhund" (or freely translated, "You are a hog's dog").

The Allies had by this time already developed and used magnetrons and klystrons for centimeter wave region, so that already prior to the German jamming of the meteric "Oboe" system thay converted to the production and installation of the centimetric "Oboe" system.

The crew of the German listening-in installation "Nürnberg" noted on 30 January 1944 signals from a "mosquito" airplane issuing from the wave region of 9 cm. The Germans did not believe that this is from a new "Oboe" system, especially since the British did not dismantle the old system, but rather used it for masking. In October 1944 the Germans succeeded in producing the jammer "Feuerberg" for the jamming of the centimetric "Oboe" system, and starting in 1945 also jammers "Post klystron" and "Roland," but without marked successes. Due to being behind in microwave technology, the Germans from the spring of 1944 to the end of the

war could not effectively counteract the Allied navigational systems.

World War II also marked humble beginnings of electronic jamming of guidance systems of radio-directed missiles.

Starting from 8 Sᵉptember 1944 the Germans bombarded Britain by rocket missiles of the V2 type, which for that time had a rather good radio-guidance system. During its flight time the rocket sent to its ground center the data on its speed and altitude. On the basis of these flight data and times the center then calculated the position of the rocket. When the rocket attained such a position that a target hit was possible, then the center by means of radio dispatched the thrust engines and the rocket sped against the target. The British succeeded in uncovering the directional guidance system and constructed transmitters for the extinguishment signals for the rocket thrust engines. By false signals they disconnected the rocket thrust engines sooner so that the rocket did not reach the desired target. The effect of this countermeasure was significant, as is shown by the difference between the rockets launched and those that reached their targets. Accprding to German data, during the7 months until the liberation of Haag, where these devices were launched, 1359 rockets of this type were launched against London. According to British data, only some 500 rockets managed to reach London. 2724 people died and 6476 people were wounded during this. This number would have been much higher if all the rockets had fell on London.

The first radio -guided air—sea rockets were used by the Germans in 1943 against an Anglo-American convoy in the Biscay Bay. The rockets were fired from the airplane DO-217. Already during the first rocket attack, one military escort ship was sunk. This weapon represented great danger for Allied convoys and Navy researchers were forced to

invent a radio-guidance system and to construct the corresponding jamming installations within as short a time as possible. This assignment was especially difficult, inasmuch as the nature of radio-guidance was totally unknown. For this reason, frequency wideband radio-receiver apparatus together with a pulse analyzer was developed. This apparatus was mounted on one of the escort ships of the convoy. By means of this apparatus it was determined that the radio-guidance system of German rockets operates at the frequency range of 40 MHz, and this with amplitudinally modulated signals on two frequencies. One of the frequencies served for the left deviation from the course, and the other for the right deviation. The magnitude of the deviation depended on on the time duration of the radio command. The first rockets of this kind (HS-293) had a flight time of 60 seconds, while with the later and improved version (FX-1400) the speeds were increased and the flight time was decreased to 30 seconds. Analysis of the guidance signal made possible the construction of a jammer. First a jammer with an output power of 50 W was produced, while later, in 1944, its power was increased to 1 kW. This was the jammer AN/ARK-8, with which 14 ships were equipped. These jammers were also mounted on destroyers "Frederic L. Davis" and "Herbert C. Jones" and they succeeded in 75 German attacks to deflect the path of more than 100 German guided rockets, or approximately 2/3 of those launched. The Germans thus lost their confidence in radio-guidance and converted exclusively to wire-guided missiles. These were varieties of flying bombs HS-293 B and C.

World War II brought also humble beginnings of radar masking technology. The Germans researched materials for their submarines, especially for installations for underwater breathing of the "Schnorkel"

type, such as would absorb electromagnetic waves, the project being called "Schnornsteinfeger." They did not achieve any marked successes in these operations.

As a good indicator of the effectiveness of individual electronic measures and countermeasures in World War II, in the European theater, served the percentage of aviation loss due to the enemy anti-aircraft defense. As soon as the losses increased, this meant that the measure or countermeasure used was detected and has become ineffective and that another measure or countermeasure, respectively, must be found immediately. Figure 4.9* shows the dependence of the percentage of loss of Allied aviation with respect to the undertaken passive or active electronic countermeasures or intrinsic errors (as has been the application of the installation for the determination of allegiance of an airplane - IFF simultaneously on all airplanes in the formation).

Electronic measures and countermeasures have been used immensely also in the Pacific Ocean war zone, only under different conditions with respect to the European war zone. The war zone in the Pacific was characterized by vast spaces, which caused the Americans to develop special tactical electronic countermeasures.

From the first days of the war through to 1942, both warring sides used radio reconnaissance of radio communications as almost the only visible sign of electronic countermeasures. On the American side, radio reconnaissance was done by units KoV and RM, and also by civilian stations of the Federal Commission for Communications located on a large number of islands and their center in Hawaii.

---

*Anton Požeg: Electronic jamming and measures for counter electronic observation, Supplement to the Aviation Journal (Vazduhoplovni Glasnik) Zemun, 1961, p. 14.

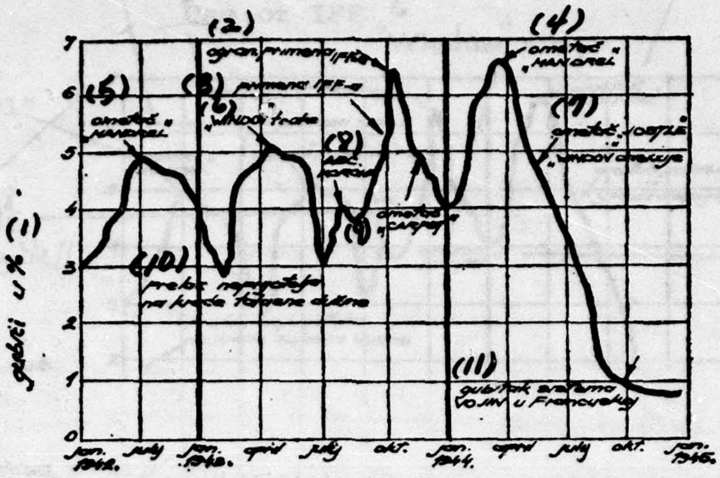


Fig. 4.9. Percentage of losses by allied aviation with respect to the radar countermeasures undertaken.
Key: (1) Losses in %; (2) Enormous use of IFF; (3) Use of IFF; (4) Jammer "Mandrel"; (5) Jammer "Mandrel"; (6) "Window" strips; (7) Jammer "Jostle" of "Window" diversion; (8) ABC [illegible]; (9) Jammer "Cartop"; (10) Conversion by enemy to shorter wavelengths; (11) Loss of [illegible] of armies in France.

By deciphering captured Japanese radiograms, with which hundreds of cryptographers and translators were kept busy, great progress was made. The captured and translated communications were multiplied so that 10 to 14 copies were available which then were dispatched to the interested institutions. In July 1941 the Japanese decoded the Japanese diplomatic code (code "rozi") and since that time were well informed of Japanese plans. A great number of the telegrams was decoded still the same day that they were dispatched from Tokio. The rapidity of the decoding was made possible also by a special device only four copies of which were fabricated. Three of them were used by U.S. cryptographic agencies and one of them was in 1941

lent to Great Britain for use. In this way, more than 700 information communications were decoded, out of which some 200 gave information regarding the movement of Japanese ships; the remaining ones were of diplomatic nature.

At the start of military operations against the United States, the Japanese fleet received several ciphers and codes which had to be used by a definite order. Thnaks to their experience with decoding the diplomatic code, American cryptographers quickly decoded the above codes of the Japanese fleet on the basis of the material received.

After Japanese attack on Pearl Harbor, the American intelligence service had at its disposal the information that the Japanese are preparing an equally large attack on a city which by their code they called "AE." It was imperative to find out as quickly as possible which city this was. The Americans arrived at the possible estimation that this could be Midway island. To confirm this proposition, they made use of radio disinformation. The commander of the island was given an order dispatch a communication to his superiors in Pearl Harbor in the opening text to the effect that the machinery by which drinking water is supplied has broken down and that the operation of Japanese radio stations is all the time painstakingly active. The radio intelligence service of the Japanese acted flawlessly. Already the third day after the transmission of the prepared text the American reconnaissance station in Hawaii received the Japanese radiogram in which it was said that the Americans have difficulties at site "AE" with respect to drinking water supply. The target of Japanese marine operation was thus uncovered. The Americans succeeded in preparing a prompt defense and on 4 June 1942 the Japanese fleet suffered a terrible defeat.

After these very successful operations the American radio intelligence service suffered a great malsuccess due to its own press. Namely, the newspaper "Chicago Tribune" published a communique that the principal role in the victory at Midway was played by the radio intelligence service. On the basis of this the Japanese grasped that their codes have been revealed and they immediately introduced new ones. Similar cases of a lack of caution in the U.S. press or their individual agencies repeated themselves many times during the course of the war and their result always was a change in the Japanese code and a new tortuitous toiling labor on the part of American cryptographers toward their decoding.

The Americans did not jam radio communications of Japanese ships and units, since it suited them better to monitor and decode the radiograms and to radio goniometrically determine the position of the ships.

The Japanese were relatively late in starting to use radar installations. The first two radars were installed on ships "Ise" and "Hega", which took part in the operations at Midway Island. The Americans were not familiar with Japanese radar equipment, so they put in tremendous effort to obtain information about it. They questioned prisoners, and carefully studied captured documents and information obtained from all the captured installations was passed on to the laboratories. During the landing on Guadalcanal (1942), the United States marines succeeded in capturing several Japanese radar installations of the newer brand. On the basis of this, a special highly sensitive monitoring receiver was developed, which in 1942 was mounted onto airplanes and ships. A modified version of it was mounted in 1943 also on submarines.

In the years 1942 and 1943 the Americans conducted systematic radio reconnaissance on the Pacific so as to uncover radio stations in the area between Solomon Islands and China. They established that the Japanese dipose of a rather strong radar network on the ground, on the ships, and on the airplanes. The results of this radio reconnaissance were plotted onto a special map which served for the preparation and development of measures for the jamming of Japanese radars, their use as radio search lights, and for finding unobserved sectors and pathways for future observations.

On the occasion of movement of troops or attack the Americans made use of signals from Japanese radars as navigational radio search lights for the guidance of their airplanes or ships into the target region. When the Japanese noticed that their radar signal is being used as a radio search light they excluded those radars as soon as they noticed enemy formations on their screens. Since the range of a sensitive radar monitoring receivers is considerably larger than that of a radar installation (the receiver receives a very powerful transmitted radar signal, whereas the radar weakens the reflected signal from the target), the American units were able to adjust the corresponding countermeasures prior to Japanese attacks. Thus, for instance, American ships received the radar signal from Japanese torpedo airplanes 30 minutes before these torpedo airplanes noticed on their radars the American ships. The case is also known where the American submarine "Batfish" uncovered radar signals of three Japanese submarines, determined their position, and sunk them one by one.

On the basis of the results of radio reconnaissance and data on Japanese radar installations, an entire series of active jammers was developed in the USA in 1943. Thus jammer AN/ART-1 covered the

frequency range from 90 to 220 MHz, having a power of 15 W, jammer AN/ART-2 covered the frequency region from 420 to 720 MHz and was used against radars for remote observation.

After taking New Guinea in December 1943, a Japanese airborne radar installation was captured. On the basis of it within a course of 7 days, 50 ship installations were modified for active jamming, whereby a tremendous blow was dealt the effectiveness of Japanese torpedo airplanes equipped with these radar sights. On the occasion of the jamming , the torpedo airplanes lost their target and became an easy prey to American anti-aircraft artillery and defense fighter planes. After this happened, the Japanese very rarely used night-time attacks.

All marine units of the American fleet operating in the Pacific were already in 1944 equipped with complete equipment set for electronic countermeasures. For destroyers and submarines is consisted of three monitoring receivers which covered the frequency region from 40 to 10,000 MHz; one pulse analyzer; one goniometer for the frequency region from 90 to 5,500 MHz, and several active jammers for frequency region from 60 to 10,000 MHz

Active jammers protected navigable units from coastal artillery directed by radar and prevented torpedo planes and flying torpedoes from finding the target and sighting by means of radar.

Prior to the end of the war almost all American airplanes which took part in the hostilities in this theater were equipped with two active jammers of radar installations. Many airplanes and flying fortresses (B-29) were also equipped even up to 18 jamming transmitters, several detection receivers, radio goniometers, and installations for analyses (Fig. 4.10). Because of the large number of built-in antennas

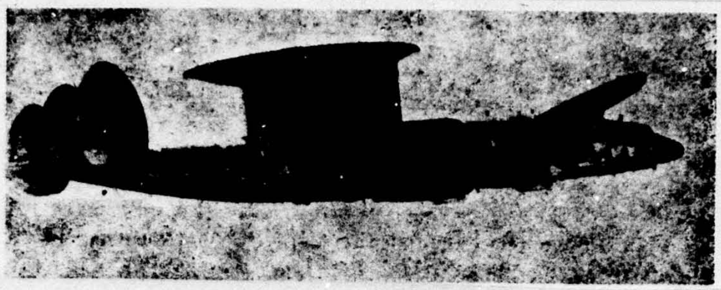


Figure 4.10.

Laboratory airplane "B-29" from World War II.

these airplanes had an unusual form (Fig. 4.10). These airplane laboratories at first made use of electronic protection of air raids, but with improved built-in technical equipment they widely used for reconnaissance Japanese electronics, in which they are to some extent a precursor of contemporary airplane and satellite systems for the detection and analysis of electromagnetic radiation.

During World War II a large number of installations for detection and jamming was produced. The main information on installations for radar detection and jamming obtained by the Americans and the British is summarized in Table 4.1.

The cited examples of electronic measures and countermeasures clearly show that electronic countermeasures have been undertaken primarily against radar and radio navigational installations. This is so because these installations played an important role in the detection and direction of fire onto the foe and on guiding to the specific regions - deep behind enemy lines - various war equipment (aircraft, rockets, and similar). Interruption of means of communication was used to a lesser degree, due to the fact that much useful information could be obtained from enemy communiques.

Experience from World War II indicates also that self-satisfaction with electronic measures and countermeasures is very dangerous, even

fatal; that electronic devices and equipment become obsolete very quickly, and that ultimately there is required continuous intensive work on the development of new methods and installations.

4.3. AFTER WORLD WAR II

The tremendous financial input and the high investment of mind and productive capacities in the area of electronics led to that during the after-war years many military electronic installations appeared and that electronics came to be used also in the fields which previously have totally been reserved for man. Armed conflicts during this period were indeed great proving grounds for practical verification of new weapons or concepts.

Already starting in 1949, the World Superpowers knew that they are insufficiently informed about the foe and his activity. Hence, intensive work on reconnaissance equipment proceeded henceforth. The application of spectral sensors, micro-electronics, and digital technology has up to the present time raised the methods and techniques of reconnaissance to such a level which in the near past has still been beyond any conception. The U.S. materiel saw the introduction of a large number of aircraft for electronic reconnaissance. Their intensive flights above the territory of East European countries started in 1950. It is assumed that during the period from 1950 to 1964 at least 26 American reconnaissance planes were downed over the territory of the Soviet Union. Public at large is familiar with the downing of their U-2 type airplane, piloted by F.G. Powers in May 1960 above the USSR territory and the reconnaissance airplane of the EC-121 type, with 31 crew members (Fig. 3.8), which was shot down by North Korean flak on 15 April 1969 above the Japanese Sea.

(1) tip uređaja	(2) frekventno područje MHz	(3) širina pojasa smetnji MHz	(4) snaga u W	
			nosioc (5)	bočni (6)
(7) a. radarski detektori				
ARQ-8	25— 100			
APRG	40—3000			
APR-5	1000—3100			
APR-8	3000—6000			
(8) b. goniometri				
APA-24	100— 450			
APA-17	300—1000			
(9) a, aktivni ometači				
ARQ-8 (Dina)	25— 100	0,15	0	40—20
APT-3 (Mandrel)	85— 150	3	12— 9	3— 2
APT-1 (Dina)	90— 220	6	0	15— 8
APQ-2 (Rug)	200— 550	7	20— 5,5	5— 1,25
APT-2 (Carpet I)	450— 720	7	20— 3	116— 0,6
APQ-9 (Carpet III)	475— 585	7	20	5
APT-5 (Carpet IV)	350—1200	2,5—3	30— 5	
APT-4 (Broadloom)	150— 780	7—10	150	
APT-9	300—2500	2— 8	25—10	10— 3
APR-10	2230—4030		25—50	
AN/ARK-8	40		1000	
AN/ART-1	90— 220		15	
AN/ART-2	420— 720			
AN/ART-3	85— 150			

Table 4.1. Fundamental data for Allied electronic countermeasure installations used in World War II.
1 - Installation type; 2 - Frequency range MHz; 3 - Width of interference band, MHz; 4 - Power in W; 5 - Carrier; 6 - Laterial; 7 - a. Radar detectors; 8 - b. Goniometers; 9 - c. Active jammers

It is thought that the mission of this second plane was to detect and monitor North Korean radio and radar network and to follow the movement and radio communications of the Soviet Far East fleet. After its destruction, President R. Nixon at the press conference (inadvertently!) stated: "All three radars (North Korean, Soviet, and American) showed the same thing ..." By this he accidentally disclosed the heretofore carefully guarded secret regarding the capabilities of the electronic reconnaissance system called "Elin."

By the development of spectral sensors and radars for lateral reconnaissance, military reconnaissance technology underwent tremendous progress. Passive infrared recording makes possible the detection of new sources of heat from conventional kitchens where food is being prepared to vehicles with engines turned on. Allegedly, the newly developed technology of highly sensitive infrared photography from the air was responsible for the capture of Che Guevara, the renowned Cuban revolutionary in Bolivian jungles. To wit, the U.S. intelligence service (CIA) which aided Bolivian authorities, that Che Guevara guerillas use a special stove for the preparation of food also used by the Viet Cong units in Vietnam. The special feature of this stove is that no smoke and no fire are seen. However, this stove radiates sufficient amount of infrared rays that it can be photographed also through the dense jungle shrubbery.

Passive infrared reconnaissance technology makes use of thermal radiation emitted more or less by all objects. Wavelengths 8-14 microns served for the recording of this radiation, i.e. the radiation of the wavelengths which the atmosphere does not attenuate. It was established that sick plants can be distinguished from healthy ones, that sea currents can be distinguished, as well as the mixing of sweet

and salty water at the outflow of rivers into the sea, motor vehicles with started engines, and even sites where such vehicles rested (thermal impression). Tests on the sea revealed that on the basis of water flows one can also determined the submirines at depths to 30 m. This method is specially suitable for the detection of nuclear submarines, inasmuch as they use sea water for the cooling of nuclear reactors (Fig. 4.11).

Figure 4.11.

Passive infrared patterns: a) warm water flows of nuclear submarine; b) IR-pattern of a submarine at a depth of approximately 30 m; c) IR-pattern of, at left the "imprint" of a tank, and at right of a truck with started engine.

The infrared recording technology has improved to such a degree that active recording is done by by scattering by means of an infrared laser beam. Extraordinary takings of the terrain flown over can be obtained (Fig. 4.12).

The development of photographic prints, as well as IR-patterns, requires that the reconnaissance plane returns to the base; in addition, the time needed to develop the film also has to be considered. In order that this time would be reduced for dispersion photographing of

the terrain, each line of the picture is transfferd to the ground by means of radio individually which then makes possible that the entire picture of the terrain can there be put together as flown over, with this being done either by photography or electronically (thermal photography or by use of television)(Fig. 4.14).

Microminiature electronic beams, radar and IR-reconnaissance systems, together with radio installations for transfer to the ground, are placed into special containers (Fig. 4.15) with own energy source. These containers can be hung onto any given airplane.

Already since 1960 the use of pilotless aircraft for the purposes of reconnaissance has been tested. Several tens of types of these

Figure 4.12.

Active infrared laser dispersion photo of the terrain taken at night from an altitude of 1500 m.

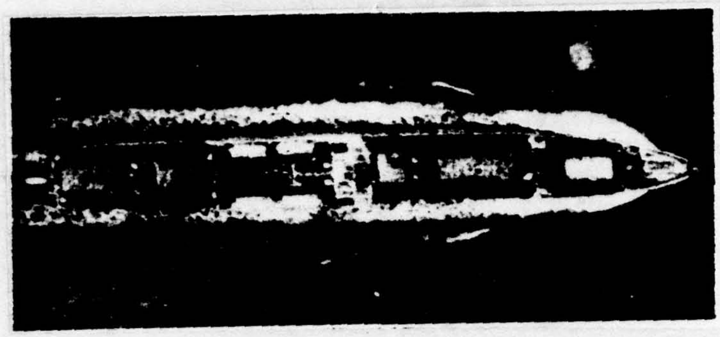


Figure 4.13.

Passive infrared photo of a ship on high seas. Due to change in temperature (cooler parts are lighter, warmer parts are darker) both the ship and the waves which it produces are visible.

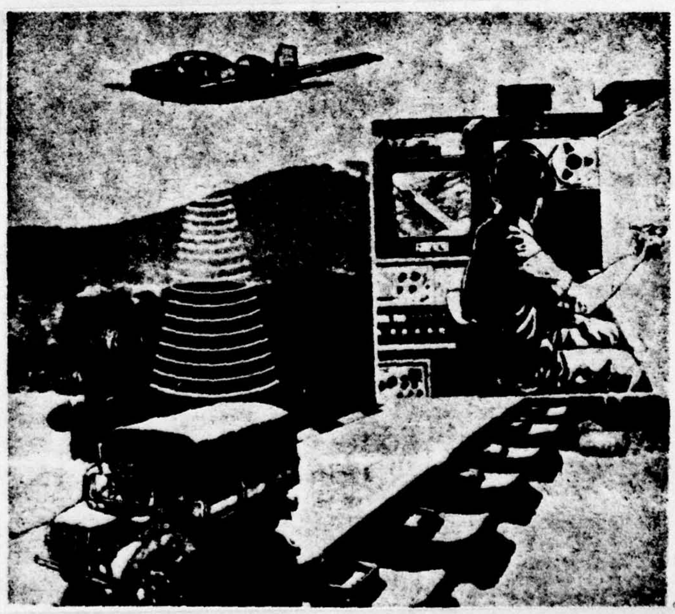


Figure 4.14.

Dispersion IR-reconnaissance system with instantaneous transfer of the picture to the ground.

aircraft containing different electronic equipment have been developed. One of the last solutions of this kind of reconnaissance sets is that with the designation AN/USD-5 (USA). This system consists of a ground cabin containing the electronic installations, a turbojet engine aircraft, a launching ramp, and an installation for returning the aircraft and its landing. The wing span of the aircraft is approximately 7.3 m, the total length approximately 11 m, the height approximately 2.4 m; the weight 3.950 kg and the lift of the turbojet engine approximately 1.350 kg. The aircraft is launched from a mobile launching ramp and it flies according to a predetermined program; during the course of its flight it can, depending on need, be either lifted or lowered. The low flight between ground objects and its high speed make difficult its detection and its being shot down by flak weapons. Since most of these aircraft are made of plastics (polyester, reinforced with glass), its radar reflex surface

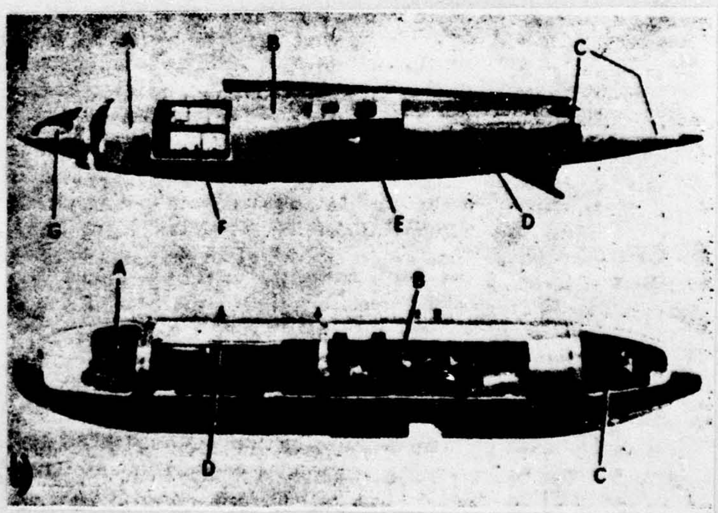


Figure 4.15.

Reconnaissance container a) for combined radar and IR-reconnaissance A - radar receiving and transmitting station, B - IR-equipment, C - power supply, D - installation for recording of radar picture and G-E - chambers, F - data converter; b) for IR-reconnaissance (A - chamber, B - IR-taking installation, C - data converter, D - recorder).

is small and therefore its detection by radar is difficult. During its flight above enemy territory the aircraft reconnoiters and by radio dispatches the information to the ground cabin in which they are converted to a picture and used for further processing in staff offices. After the completion of its mission, the aircraft slows down its flight and settles on the ground by means of the parachute or langing balloon (on its wings or the body). By helicopter or vehicle it is then taken back over to the landing ramp for reuse.

During the Korean war, electronic reconnaissance and countermeasures were of secondary importance. Surface-to-air rockets were unknown, radar-directed anti-aircraft fire was rare, and mostly the few remaining radar installations from World War II were used for this purpose or their immediate descendants. A higher degree of development and use experienced radars for the detection of mortar positions. However, it is only during the Vietnam war that electronic countermeasures were massively used, both in strategic and in tactical operations.

With the commencment of the bombing of North Vietnam, the American Air Force was unprepared with respect to electronic countermeasures. The combat airplanes were not equipped with electronic protection devices, and therefore suffered great losses from North Korean flak. For this reason, the American Air Force started in 1965 to equip airplanes of the F-100, F-105, and RF-4C type with electronic self-protecting devices. These made it possible for the crew of the airplane to be warned if they were present within the radiation beam of acquisition of guidance radars for surface-to-air rocket systems, acquisition or sight flak radars or autopilot airborne radars;

- to warn the crew that a surface-to-air rocket has been launched onto the airplane, on the basis of the change in shape and level of

the primary guidance signal;

- automatic goniometration of the radiation source and its use as navigational search light to reach the target region.

Electronic self-protective devices turned out to be extremely useful and were integrated into at least 4,000 airplanes of the type F-100, F-105, RF-4C, B-52, C-130, C-119, and C-47.

North Vietnamese forces parried American self-protective devices:

- by protecting the warning receiver at the instant the rocket was launched by a false transmitter which forced the airplane to unload the airplane or to launch the bait rocket (due to limited carrying capability, only 1-2 of them were on board) or that it starts the maneuver to escape the rocket;

- by the use of the known imperfections in the installations and their use as radio search lights or concentrating the flak equipment at the forecast flight direction;

- by introduction of maximal radio silience in activation radars and in radars for the guidance of surface-to-air rockets.

All this was accomplished by effective combination of air observation systems and by the use of its data for rocket system activation.

The Americans' response was in the nature of the introduction of a supersensitive narrow-band receiver capable of uncovered also the "silent" radars (radars capable of serving as artificial antennas in their preparedness state) and using them as navigational search lights. The receiver makes use of a tube for progressive waves as an amplifying component and under the designation AN/ALR-31 (SEE SAM program) it is integrated onto the F-111 A type airplanes. It is used by that radars in their "preparedness state" operate with transmitters connected to artificial antenna loads, and these loads are not ideal, but are rather somewhat lighter. If this parasitic radiation is

is minimal (up to 1%), this is nevertheless sufficient to register a supersensitive receiver (1% of 1 MW equals to 10 kW, which is a considerable power).

On the Vietnam battlefield a role was reserved also for the jamming of enemy electronics. From specially equipped airplanes for active electronic reconnaissance and jamming, such as B-52, B-58, B-66, EC-121, RB-66, and others, a changeover was made to the equipping of combat airplanes and installations for active electronic protection.

Specially equipped airplanes with tactical remote jamming (outside the range of the enemy anti-aircraft defense) provide electronic protection of own formation from enemy electronics (Fig. 4.16). By intensive flights outside the range of the anti-aircraft defense one strives to saturate the capacity of the enemy electronics (the transfer and processing systems are capable of simultaneously processing only a limited number of data). The attacking group formation approaches the object to be attacked in low flight.

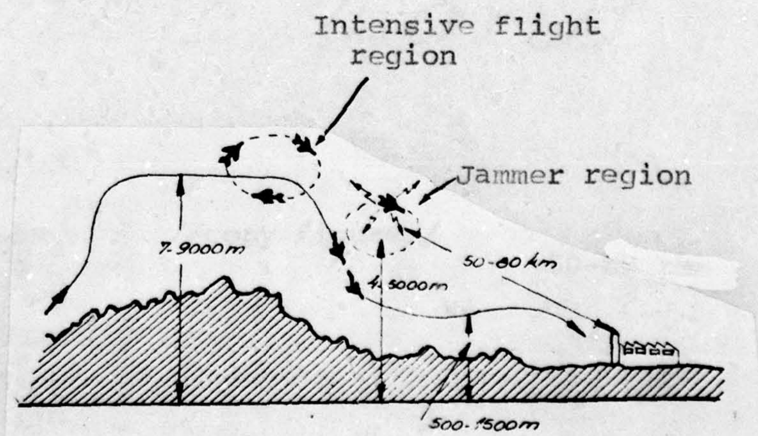


Figure 4.16.

Characteristic tactical application of an American jammer airplane for the protection of strike formations on an installation in Vietnam.

AD-A083 358 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/4

ELECTRONIC COUNTERMEASURES,(U)

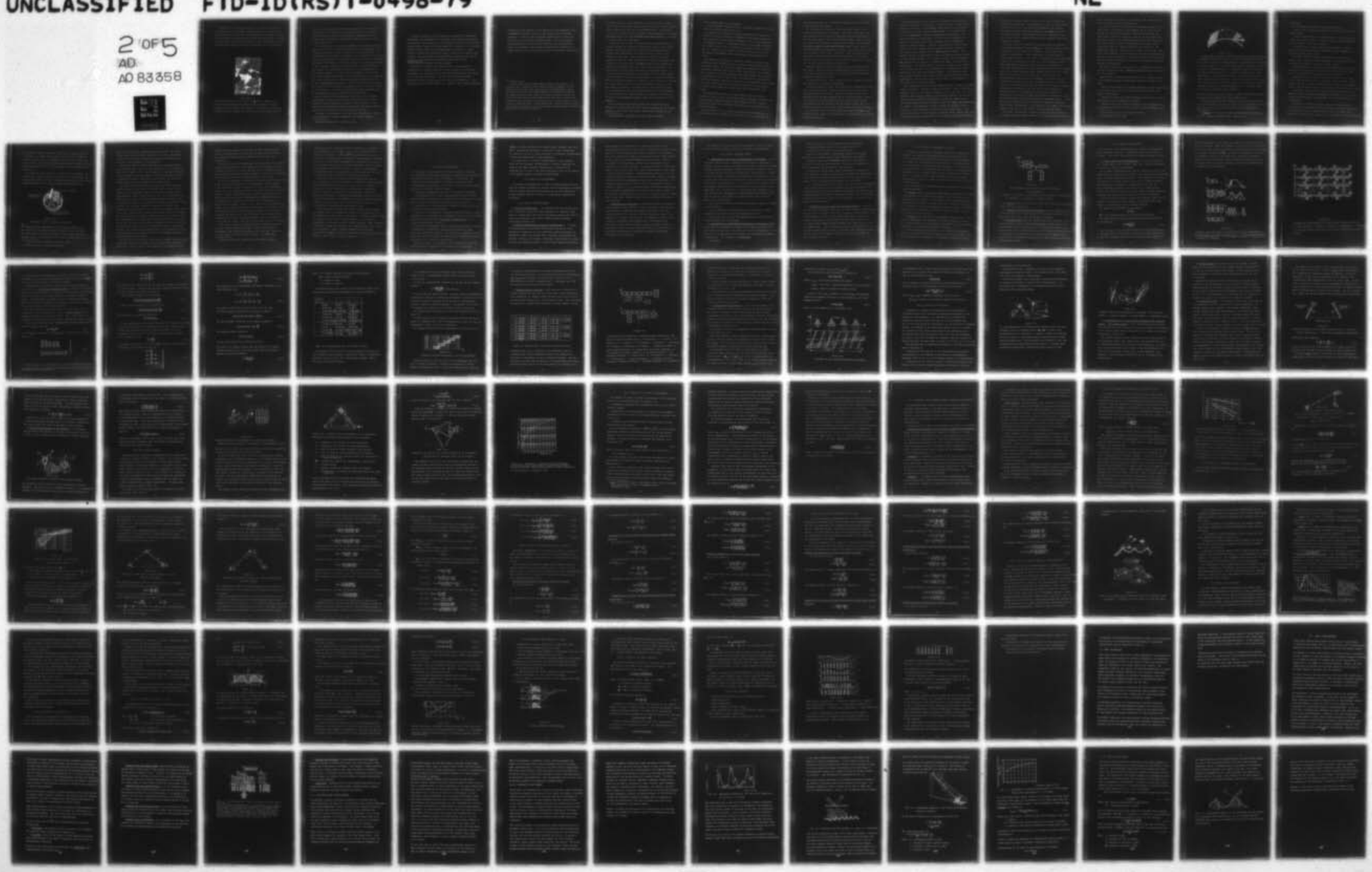
AUG 79 A RAZINGAR

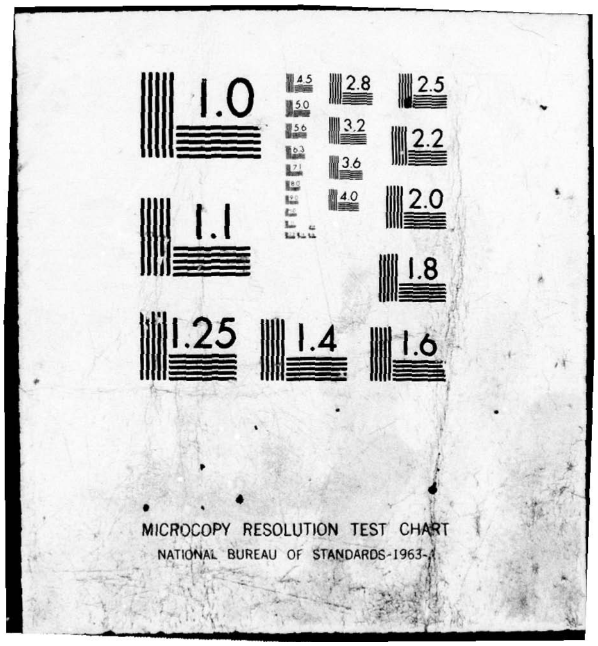
UNCLASSIFIED FTD-ID(RS)T-0498-79 NL

2 OF 5

AD

AD 83358




1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Increased air actions above North Vietnam required a change in the tactical use of electronic countermeasures on the part of the United States Air Force, since remote jamming was no longer effective due to improved electronics on the part of the anti-aircraft defense. For this reason, they integrated into the combat airplanes electronic countermeasure equipment and used this directly in the operations.

Figure 4.17.

Four fighter bombers of the F-105 D typeled by a modified EB-66 bomber (in the center of the photo) at the occasion of "blind" bombing of North Vietnam. The airplane EB-66 serves for electronic protection and for guiding the formation toward the target region.

Thus to every formation of four fighter bombers there was added one airplane for the creation of an "electronic shield"; in addition, this generally also serves for electronic reconnaissance of the terrain and for guidance of the airplane toward the target of the attack (Fig. 4.17).

The next phase in the electronic countermeasures used by American forces on the Vietnam battlefield represents the introduction of the "Advanced Wild Weasel" system (acquired also by NATO forces). The application of this system was possible by the technology of integrated beams and microminiature electronics, which in 1967 left the laboratory framework. The essence of the system consists in modular construction of the electronic countermeasure installation and the outfitting of the airplane by installations necessary for the accomplishment of the assigned mission. The system has two versions. In the first one the electronic installations are an integral part of the airplane, and in the second they are mounted in special autonomous (relative to their power supply) containers, similar to additional fuel tanks. The length of these containers is approximately 4 m, and they measure 25 cm in diameter. At the present time there exist containers with the designations AN/ALQ-71, AN/ALQ-76, and AN/ALQ-100.

Harried development and outfitting of NATO units by electronic countermeasure equipment was even more hurried after the airborne landing of Soviet Army*units on Prague in 1968, because all the closest radar observation stations and stations for missile guidance operated by the NATO forces were paralyzed by jamming.

Electronic reconnaissance is not done only from the air. Having the corresponding equivalent equipment, the vehicles which are

*Wehr und Wirtschaft No. 5, 1969, p. 299.

Electronic equipment of these ships makes possible the detection, monitoring, and localization of electronic installations and systems, in particular those which due to the frequencies used or their peculiar antenna systems cannot be detected beyond the horizon or at an altitude (coastal radars, radio relay communications, and similar). Radio traffic is intensely monitored not only to determine the number, kind, location, and peculiarities of communications equipment, but also for the sake of registering and classifying individual peculiar characteristics of individual participants in radio traffic.

The ships are equipped with oceanographic research equipment (including here also sea cruisers) for the testing of sea currents, temperature, and salinity of water and their dependence on the season, time of the day, and similar. All of these investigations have a primarily military nature for the safe movement of submarines. Also determined are the "deaf" regions, i.e. those in which sound propagation

patrolling in the vicinity of the borders are also monitoring radio communications traffic. Still the most suitable for "electronic espionage" - which is what electronic reconnaissance is called in some places - are specially equipped ships* - due to the larger carrying capacity of greater energy sources, more places where to install the antennas, higher number of experts, the possibility of longer holding times in the coastal belt of international waters, etc.

---

*Around 1965, the USA had at their disposal three ships of the "Pueblo" type (belonging to the National Security Council) and five ships of the "Liberty" type (belonging to the United States Navy). The public found out about their existence when North Korean forces in 1968 captured the ship "Pueblo" in their territorial waters, and at the time when Israeli forces sunk in the Suez Canal a ship of the "Liberty" type (for which it is believed that in this conflict of 1967 played an important role). At the present time, they are using more and more electronic equipment mounted onto ships of various types (military, commercial, tourist, and similar).

is either weakened or made difficult, the parts of the sea with such a surface temperature picture that covers up the thermal picture of the submarine for the case of ir-reconnaissance, and similar. Also present on these ships is equipment for photographing of specific underwater noises which are produced during the movement of all kinds of military ships and submarines.

Towards the end of 1950, the opinion prevailed within the U.S. military circles that classical anti-aircraft artillery has become obsolete and that it should be replaced by guided surface-to-air rockets. This substitution commenced also in the Armies of the countries of the West. Thus, for instance, there were in West Germany in 1957* out of the anti-aircraft artillery batallions (648 fieldpieces L-70 Bofors with 248 installations for the guidance of Contraves--Fledermaus) which were replaced by 24 batteries of the "Nike Hercules" rocket and 36 batteries of the "Hawk" rocket. As a result of this substitution, the priority of the classical anti-aircraft artillery also ceased, which however retained its position due to its higher properties in actions at lesser altitudes. Besides, the rocket systems are tied in with the position (they are either less mobile or immobile) and depend on the radar observation with all the shortcomings that this entails (horizontal and dead zones). On the other hand, the rocket systems made possible the defense all the way to the atmospheric boundary, which is by classical flak not possible.

The protection by such rocket systems can be pictured as the bounding of a garden with the total growths measuring 10 m in height, starting at 30 cm above the ground, through which opening all the

*Wehrtechnische Monatshefte, No. 2/3, 1968, pp. 41-48.

harmful pests manage to get through.

In the conflicts following the war, aviation recognized well this fact and naturally used it well too.

In Korean War in 1950/1951, the greatest number of losses were inflicted upon the Americans by airplanes of the Soviet production line MIG-15. The Allied ground flak downed 1,213 of them and damaged an additional 3,000. In subsequent months, the Americans prohibited all aircraft from flying at altitudes lower than 2,000 feet (about 666 m). Flight at low altitudes at that time did not yet receive its right to citizenship, since anti-aircraft rockets did not yet exist.

Only during the Vietnam War, during the bombing of North Vietnam territory, there commences the use of guided surface-to-air rockets of Soviet origin. The first such rocket was launched on 4 July 1965, and thourgh February 1967, some 1,500 of these rockets were launched. The percentage of American airplanes shot down through this amounted to approximately 2.1%. North Vietnam had concentrated approximately 3,025 anti-aircraft guns for the defense of more important installations. The radar network was formed by some 116 radars for air observation at various wave lengths and approximately 136 anti-aircraft sight radars.

Such anti-aircraft defense of North Vietnam forced the United States Air Force to change its flight tactics. Intensive countermeasures are undertaken against electronic installations, and the airplanes started to fly at lower altitudes and in such a way as to make use of radar dead zones.

The experiences of the American aviation from the Vietnam War are being utilized by the aviation of all armies, as can be seen from the

the high percentage of low-flying training and in the overall flying training psychology.

The short-duration Sinai war (5-10 June 1967) confirmed the advantages of low-flying technology. With their lower number and qualitatively weaker aviation the Israelis achieved domination of the air space within 2 hours and 50 minutes total. This is all the time they needed to destroy Egyptian planes (mostly on the ground) and radar stations on the Sinai Peninsula and in Egypt proper, by carefully planned and synchronized action. After this, they executed an air attack on Iraq, Jorda, and Syria. Until the night of the second day of the war they already destroyed 416 Arab airplanes (393 of these on the ground). On the sixth day the Arab air forces were for all practical purposes nonexistent.

Both the Israeli and the Arab airplanes flew at altitudes less than 100 m. Where the terrain allowed this, the planes flew even at altitudes between 50 and 15 m. Under high flights both sides considered flights above 100 m.

The attacks were, as a rule, executed by four airplanes in tight succession, but in different directions.

Low-flying airplanes were en masse uncovered by acquisition radars, however for broadcasting the data to sight radars and for their utilization there was no time. There are recorded only several downings of the airplanes through the use of sight radars. Most of the airplanes were shot down by means of optical sight devices. Identification of the airplanes was exclusively visual, due to the low flight altitude, high speed, and briefness of the time available.

The experience from the Israeli-Arab war showed that every anti-aircraft defense system is useless unless it provides defense against low-flying airplanes.

From what has been stated above one can conclude that low-flying airplanes represent a latent danger. For this reason, intensive work is going on to create a corresponding countermeasure, in particular in the form of an anti-aircraft guided rocket. To satisfactorily solve this assignment, numerous construction, technological, and systemic problems must be solved. All the missiles produced as of now have a relatively high initial inertion and an inadequately efficient guidance system. A typical representative of this is the American "Red Eye" rocket, which is launched from the shoulder of the soldier and is equipped with an IR-autoguidance system. The negative property of this rocket is its low effectiveness when aiming at a low-flying airplane in the encounter course since the frontal IR-radiation by the airplane is insufficient for the ir-head for autoguidance. The British rocket "Blow pipe", which is to be adopted as an armament in 1970, uses autoguidance as a condition for visual tracking of the rocket and airplane flight. It is considered that the guidance accuracy shall be low, for it is difficult under battle conditions to hold both the target and the rocket simultaneously in the cross at the end of the sight.

Still during World War II it was established that a surface-to-surface rocket can become an powerful weapon for surprise, rapid, and powerful strike on the foe. The rockets of that era (V-1, V-2) had a low aiming accuracy, low carrying capacity, poor systemic guidance, and complex, costly, and an unreliable construction. During the postwar period first both superpowers (USA and USSR) started the design and construction of powerful intercontinental missiles capable of carrying a nuclear warhead at great distances and onto the distant target there. They were later joined by Great Britain, Nationalist China, France, and Japan. With respect to that guided missiles are guided by means of electronic

devices, it is also in this area that a real war of systems and countersystems exploded. Its consequence is that there have been up to the present time developed and constructed many missiles and defense systems, which become obsolete much sooner than they are tested and used. Both superpowers saw the senselessness of such a race and hence started the agreements regarding limitation of stategic weapons.

The first strategic missiles were ballistic with the guidance at the initial portion of their itinerary. Their appearance echoed the problem: How to uncover the frequency at which this radio guidance is being done. These frequencies are being guarded as a top military secret. A scientist, an astronomer from an observatory in Ohio, USA, accidentally by means of a radio telescope received from Constellation Adromedis radio signals at the frequency of 1,400 MHz. This discovery was kept secret since this were the guidance signals for Soviet intercontinental rockets emitted from the rocket base in the vicinity of the Caspian Sea. Radio guidance of intercontinental rockets became unreliable. From 1960 on, it was replaced by gyroscopic or inertial autonomous systems. For both systems it is characteristic that the rocket flies along an assigned preprogrammed itinerary and that by means of the gyroscope or inertial sensor the deviations from the assigned itinerary are measured and the necessary flight corrections are introduced. Here, the inertia system is more precise than the gyroscopic system. Among this type of missiles we have "Minuteman", "Polaris," "Poseidon," "Atlas" (USA), "Bluestricke" (Great Britain), SS-9 (USSR), and others, having a range greater than 5,000 km and with nuclear heads.

The defense against these missiles necessitated the creation of a powerful far-range radar network of early warning and the creation

of an effective weapon for the destruction of the missile or at least to deflect it from its itinerary.

The United States set up powerful radar stations along a belt from Alaska to Greenland to Great Britain for the sake of early warning for rockets which might be fired to American from the Soviet Union across the North Sea. This is the well known BMEWS (Ballistic Missile Early Warning System)* system, which is all the time complemented by modern installations and extends in the directions across the Equator and toward the South Pole. The fundamental principle of this system is given in Fig. 4.18. This system makes possible early detection of ballistic intercontinental missules and their destruction by an antirocket with nuclear head. The USA possesses antirockets of the type "Nike—Zeus," "Nike—X," "Sprint," and "Spartan."

The Soviet Union has a similar system - "Galoš" and "Grifon"** . Rockets of this system were exhibited during the parades in Moscow in 1967 and 1968.

During their operation the anti-rocket defense systems make use of the following phenomena which appear during the flight of the rocket:

- drive engines during the operation increase electron concentration in the exhaust gases jet, as a result of which the radar reflex surface is increased;

- during the flight the rocket changes its radar reflex surface independently of the position in the space;

- during reentry into Earth's atmosphere, due to increased speed and associated with this, increased friction and temperature, there

---

*Early warning system for ballistic rockets.

**Designations used by NATO.

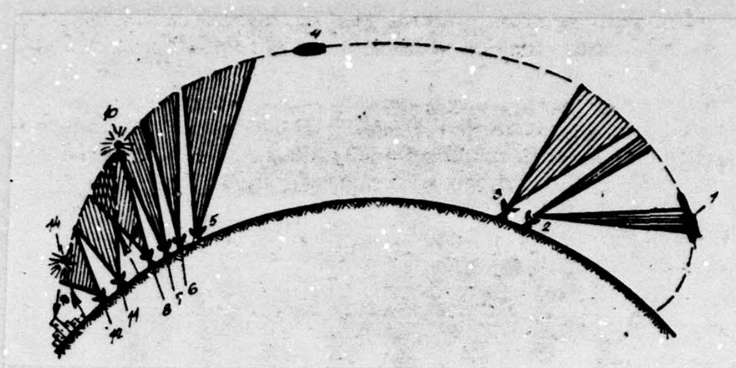


Figure 4.18.

Defense system against ballistic intercontinental rockets (USA)*
1 - ballistic rocket in flight; 2 - remote warning system radar of the BMEWS; 3 - radar for determination of rocket itinerary coordinates; 4 - rocket warhead; 5 - radar for acquisition of anti-rocket system; 6 - radar for identification; 7 - radar for tracking the target of the first antirocket system; 8 - radar for guidance of the first anti-rocket; 9 - first anti-rocket; 10 - encounter point of the first antirocket and warhead; 11 - radar for tracking the target of the second antirocket system; 12 - radar for guidance of the second antirocket system; 13 - second anti-rocket; 14 - encounter point of the second antirocket and the warhead.

is created around the rocket warhead a plasma cloud which increases its radar reflex surface by several hundred times;

- nuclear explosion of the antirocket near the warhead effects on it in two ways. By means of a shock wave it interferes with its itinerary, and by means of ionized radiation it disables its

---

* Handbook of the bases of radio-locationalization technology, p. 719, Military Publishing House, Moscow, 1967.

electronics.

The following have emerged as the countermeasures:

- special fuel additions to decrease the number of electrons in exhaust gases;

- flight stabilization of the rocket over the entire itinerary, so that its surface exposed to radar observation would provide the smallest possible radar reflex surface;

- designing such a warhead shape which would have a minimal radar reflex surface and upon reentry into Earth's atmosphere the smallest possible plasma cloud;

- creation of such a warhead which would upon reentry release several false warhead in various directions and thus forced the foe to activate anti-rocket defense to several targets;

- adoption of such a warhead type which would increase its speed during the last part of the intinerary, so that the already short time for anti-rocket defense would become even shorter;

- adoption of such a warhead which would during the last phase of the flight divide into several warheads aimed at various targets (system MIRV, for "Minuteman" rockets, with 3 heads, and "Poseidon" rockets, with 10 heads, tested at Cape Kennedy Proving Grounds in 1968);

- outfitting warheads with electronic jamming equipment for the jamming of enemy electronic observations and guidance and, ultimately, finding warheads which at the last phase of the flight could fly at low altitudes.

With respect to that the American antirocket defense system is aimed against intercontinental rockets launched across the North Pole, the Soviet Union also in 1968 developed a system of global intercontinental rockets. These rockets are a combination satellites rockets.

The rocket is launched across the South Pole and during that time represents a satellite of the Earth. When it enters a position suitable for the attack it converts into one or more rockets with nuclear heads. The system came to be called FOBS (Fractional Orbital Bombardment System*) and it acts according to the way presented in Figure 4.19.

The tests have been performed in "Kosmos" type satellites. It is known that "Kosmos" satellites No. 185, 198, and 209 during the flight changed their itinerary, which would correspond to the orbital bombardment system MCBS (Multiple Orbit Bombardment System**).

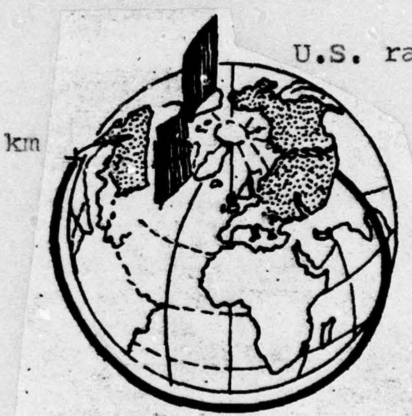


Figure 4.19.

Bombardment system by means of satellites

The progress in the technology led to that since 1962 the secret war between the superpowers has been transferred also into Space. The Soviet Union is using as "sky spie" certain satellites from the "Kosmos" series. Up to 1968 the Soviet Union launched 256 satellites,

---

* System of partial bombardment from the orbit.

** System of multiple orbital bombardment.

while the United States launched 455 cosmic objects. The data on military satellites and their missions are of a very confidential nature, and it is very difficult to define their missions just on the basis of the itinerary of the satellite.

Since March 1962, the Soviet Union has been launching "kosmos" type satellites from a base near the Caspian Sea. The launching is done under an angle of 49° to the Equator, and thus their itinerary orbital crosses the USA and Canada. After the completion of their reconnaissance mission - which lasts 8 to 10 days - the satellites descend somewhere in the interior of the Soviet Union.

The United States has satellites of the "Samos" (Satellite and Missile Observer) type, which are equipped with receivers for the control of electromagnetic radiation (detection of radar, radio communications, rocket guidance signal, etc.) on the territory over which they are flying, and precision photo-cameras allegedly with a resolution less than 1 m. During the time that the satellite flies over the U.S. territory it drops a cassette with magnetic tape recordings on the command from the Earth, also including films, which is then by a special system contained and brought down to the ground. The latest achieved development of this system is the satellite with the designation 920-A, equipped with modern photo-devices. By their use one can presumably obtain from an altitude of 150 km clear prints of any street in any town and even identify the type of automobiles on them. One American expert claimed that a near consequence of these satellites soon to be realized may even be the possible "reading of foreign newspapers" from space.

The U.S. Navy sent into orbit more than 10 "transit" type satellites, intended to provide navigational aid to military ships, especially submarines. With the help of these satellites the submarines can,

without having to surface, at the depth of their antenna systems receive the signals from the satellite and with the help of their own electronic computer they can rapidly determine their own coordinates.

The U.S. Air Force has "Midas" type satellites, which are equipped with infrared sensors for the recording of the launching of intercontinental rockets due to early warning of their antirocket defense. This satellite records all thermal radiation on Earth and it transmits these data by radio to the receiving station on the ground.

The ever more intensive development of military orbital installations caused also the development of the corresponding countermeasures. In the USA several leading manufacturers, namely RCA. Westinghouse, Hughes, etc., are occupied with this. Satellites have been developed which are capable of approaching the "undesirable" satellite, and which can by means of their electromagnetic and IR-sensors determine its function (at a distance of 10-30 km) and, if necessary, can destroy it by launching a rocket at it. After the completion of its mission such an antisatellite uses the remaining of the thrust energy for braking, so that it would as soon as possible reenter Earth's atmosphere and burnt there. The Earth radar system SPADATS (Space Acquisition, Detection and Tracking System*) tracks the flight of all satelliteees, sondes, and rocket remains above the U.S. territory.

In the area of military telecommunications significant progress was also achieved during this period. Using microelectronics technology, radio installations became small and light, they don't use much energy, and they are very reliable. New modulation

---

* System of detection, acquisition and tracking in Space.

techniques have been introduced which facilitate the recording of the communication in real time, i.e. in the transmission time.
SW VSW
Advanced and improved are KT and VKT transmitters and receivers by the use of various kinds of modulation and parametric amplifiers. For remote communications, tropospheric transmitters and receivers for jumps higher than 100 km have been introduced, as well as radio relay communications through ground or satellite interstations. Also introduced have been compressors of information with the aid of which the actual emitting time is shortened manyfold.

Modern armies have all kinds of communications, but they use them according to need and conditions. To guarantee mutual operation of various installations and systems, more and more attention is being paid to their compatibility in this regard. A sufficient number of channels is provided in each direction. Systems for automatic restoration of important communications in case of failure of some direction have been introduced. In order, however for these failures to be even fewer, there are ever stronger requirements re quality and reliability of communication means.

On the Vietnam battleground, this great military proving ground, all possible types of communication means, at all frequencies and technologies, have been used. A new concept of treating communications has emerged: namely, that all communications - be it satellite, tropospheric, radio relay or cable, global, regional, local, strategic or tactical, military or civilian - are a single unique system with great flexibility. Such a position underlines the excellent collaboration of army and civilian institutions and, on the other hand, requires a great number of systemic experts.

V ELECTRONIC RECONNAISSANCE

The general characteristics of military actions is that they are following the rules and conditions of incomplete and insufficient familiarity with enemy plans, intentions, or procedures. The objective of the reconnaissance in general, and of electronic reconnaissance in particular, is to reduce this state of not knowing the enemy to the least possible measure.

Electronic reconnaissance can have two fundamental functions:

- reconnointering the terrain, installations, units, and their mobility along the terrain at all times of the day and their operation under all weather conditions, using electronic means, and
- localization of the arrangement, numerical strength, kind, and usability of enemy electronic means.

Since for the undertaking of electronic countermeasures of primary importance is the knowledge of the properties of the enemy electronic systems, we understand under electronic reconnaissance term the second above-described function.

Electronic reconnaissance uses the reception technology by special installations of transmitter electromagnetic signals of enemy electronic equipment or systems. The immediate or follow-up analysis of the thus received signals are determined the tactical or technical properties of the equipment reconnoitered.

Besides electronic reconnaissance, the information on the kind, numerical figure, application, and location of the electronic

devices are being obtained also through agency, sabotage, and other ways. Although the importance of this type of data accumulation is important, and are at least equivalent to electronic reconnaissance, we shall not discuss them in this monograph.

The final goal of electronic reconnaissance in the technical sense are the following: determination of tactical importance and value of the enemy electronic installation or system and the evaluation of its role in the given situation, as well as the source of the optimal means of electronic countermeasure.

5.1. GOAL OF THE RECONNAISSANCE

By electronic reconnaissance of enemy electronic devices various data are obtained regarding the latter, which can basically be divided into two groups: data which characterize the tactical application of the electronic device, and data on technological properties of the device.

5.1.1. DATA OF TACTICAL NATURE

a) Kinds of systems used. - By reconnaissance one can determine which electronic systems the enemy possesses; for instance, which means of communication and at which wavelength regions, what kind of radio relay apparatus, what kind of radars, guidance systems, navigational systems, etc.

b) Numerical strength and location of systems used. - By means of substantiating the uncovered installations and by use of the statistical methods one can with sufficient accuracy determine the approximate number of activated enemy electronic installations and systems. Normally, the density of electronic installations is higher in urban and industrial regions, around military bases and airports,

and alongside state boundaries. By knowing the number of the installations one can to a degree draw a conclusion as to the military nature of the given installation and the strength of its defense. Thus, for instance, the number of anti-aircraft sight radars attests to the number of anti-aircraft batteries, and similar. However, the number of installations by itself is not sufficient for an estimation of the enemy strength. It does not suffice to state that within a given region there are 6 search radars having a large range, 1 radar for rocket guidance, 2 communications centers, etc., but one must also define the location of each one of them, within an accuracy allowed for by the reconnaissance system used. The positions of the uncovered installations are plotted onto a geographic map and are constantly updated. It is necessary thereby that these installations for electronic reconnaissance are such that they cover at least all the frequency possibilities of the enemy. The analysis of the terrain must be such that a hundred-percent cover is provided within short time intervals.

c) Forecasting of operations. - Increased activity of electronic installations, already toward the lines, may signify increased unit concentrations, preparation for action, importance of the given region with respect to security, indirect preparation prior to the launching of a missile, and similar. By systematic tracking of the movement of individual installations and by identifying their allegiance one can within sufficient degree of accuracy track the movements of units, by which their intentions can be revealed. By monitoring and decoding of communiques, valuable intelligence information can be obtained.

The obtention of this kind of data represents in wartime actions one of the most important missions of electronic reconnaissance.

5.1.2. DATA OF TECHNICAL NATURE

a) Confirmation of the ;evel of technological development. - It is customary that the enemy - depending on his degree of development - replaces his old equipment with the new one, which in itself frequently contains radically different methods and solution techniques, and it is natural that he would desire to keep these things secret. Because of this, electronic reconnaissance devices must be conceived on such a grand scale that they can envelop within their capabilities also these new systems and installations. It is most desirable to uncover these new methods, installations, and systems while they are still in the laboratory stage, for then there is sufficient time remaining to in time undertake the corresponding countermeasures. Concomitently with this is also the accompanying fact that they can them be kept in secrecy very difficultly:

- due to the large number of experts and coworkers which are engaged in such missions,

- due to radiation of electromagnetic waves during the testing phases which may cross territorial boundaries, and also

- due to that the potential development centers, in particular of small countries, and mostly known.

b) Confirmation of technological properties of electronic devices.- Under this is understood the decoding of the shape and modulation of the received signal and, on the basis of this, the determination of the kind and the technological data regarding the installation or system reconnoitered. The following are established:

- wavelength;

- type of modulation and its purpose and its legitimacy;
- antenna radiation diagram and its polarization, and
- strength of the signal at the reception site.

In case of radar systems, navigational systems, and guidance systems, the following data are also additionally established:

- duration, shape, and repetition frequency of the signal, on the basis of which one can determine: the range and capability of remote separation and the nature of data display;
- width of the antenna beam, speed, and nature of searching the space; knowledge of these parameters makes possible the determination of the angular separation capability and by it the kind, time, and purpose of the reconnoitered installation are determined;
- the remaining characteristic properties, such as the polarization of the emitted waves and their frequency spectrum, the shape of the radiation diagram and their orientation directions, the series of the transmitting pulses and their legitimacy relative to the wavelengths, repetition frequency and phases, etc., supplement or complement the picture already obtained.

c) Establishment of the degree of electronic defense. - With the goal in mind of providing optimal use of own electronic countermeasures one must know the method of the enemy electronic countermeasures, such as for instance, against a radar installation which localizes the targets on the basis of their speeds it makes little sense to use as countermeasure passive dipole corridors (see Point 9.1.3., p. 233 of original copy, p. 268 of translation): or, if the enemy has at its disposal missiles which make use of radiation from electronic devices such as radio search light, it would be very naive to further use such electronic devices.

5.2. ELECTRONIC RECONNAISSANCE TECHNOLOGY

Electronic reconnaissance technology makes use of specifically sensitive and specially wide-band receivers in combination with special antenna installations which, besides their wide-bandedness, also enable the determination of the direction. The output signal from the receiver is displayed on the indicator. At the same time, the signal is led to the analyzer, for the sake of its instantaneous analysis, or on a recording device (of the magnetic tape or similar type). The signal this recorded is analyzed later at a suitably equipped site. Figure 5.1 shows the general block schematic of such an installation.

The components of the installation must correspond to the following basic requirements:

The <u>antenna</u> must be wide-banded, with minimal side fans and of such a construction that accurate determination of the direction of the primary signal is possible. With respect to that installations for electronic reconnaissance are mainly mounted on aircraft, the size of the antenna must be correspondingly adjusted to this. Since these requirements can generally not be met by a single antenna, the use of several of them is common.

The <u>receiver</u> must have as wide as possible frequency range, a high rate of adaptability over this range, as high as possible accuracy in the determination of primary signal parameters, as high as possible selectivity, and as high as possible sensitivity.

Its most important characteristics is the width of the frequency range. It is desirable that the frequency range of the receiver for the reconnaissance corresponds to all frequencies used by the enemy.

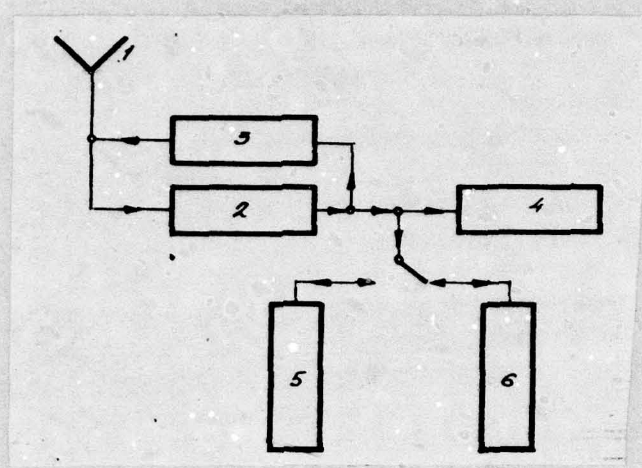


Figure 5.1.

Block schematic of the installation for electronic reconnaissance:

1. antenna, 2. receiver, 3. component used for direction determination, 4. indicator, 5. analyzer, 6. recording device.

The analyzer analyzes the received signal and determines its spectral, energy, and time parameters.

The component for direction determination must be so designed that it makes possible fast determination of the direction (within a very short time) and with as great an accuracy as possible.

The recording device must make possible unaltered recording of the received signal together with all the geographic flight data of the reconnaissance device (itinerary of the reconnaissance device; directional angles of the goniometrization of the reconnoitered installation).

Sometimes the recording device is replaced by an automatic radio system for the broadcasting of the received signals into the electronic reconnaissance center.

5.2.1. FREQUENCY DETERMINATION

The receivers of the installation for electronic reconnaissance perform frequency analyses. Essentially, there are two kinds of receivers: with direct amplification, and superheterodyne receiver.

a) Receiver with direct amplification has a smaller sensitivity and a higher width of the frequency range and a smaller selectivity; it also is of a simpler construction.

Due to weaker amplification this type of receiver is used for the determination of strong signals (such as, the reception of navigational, radar, or various directional signals). The execution of this type of receiver can be single-channel type, with or without pretuning (preadaptation), two-channel, or multi-channel (see Fig. 5.2). In case of two-channel version, the filters at the output and the receiver are attuned to the lower and the higher frequency boundary. A cathode tube with calibrated screen can be used as indicator.

In case of multiple-channel version, the frequency region of the receiver is divided into narrow ranges, of which frequency width depends the determination of the primary frequency.

The width of the permeable filter range is

$$\Delta f = 2\delta f \tag{5.1}$$

δf is the assigned accuracy in frequency determination

The number of the required filters and hence also the channels is obtained from

$$n = \frac{f_{max} - f_{min}}{\Delta f} \tag{5.2}$$

f_{max} and f_{min} are the limiting frequencies of the search region.

The shortcoming of multi-channel direct receivers exists in that for the wide frequency range and the relatively large accuracy in

the determinations, a large number of channels is required for this type of receivers. Thus, for instance, one already needs 149 channels for the frequency region from 20 MHz to 3,000 MHz and with the accuracy of frequency determinations $\delta_f = \pm 10$ MHz. The advantage of this type of reception, relative to the loss in time expended by frequency search and the problems which arise in connection with this in case of superheterodynic receivers, exists in instantaneous simultaneous reception in all the channels.

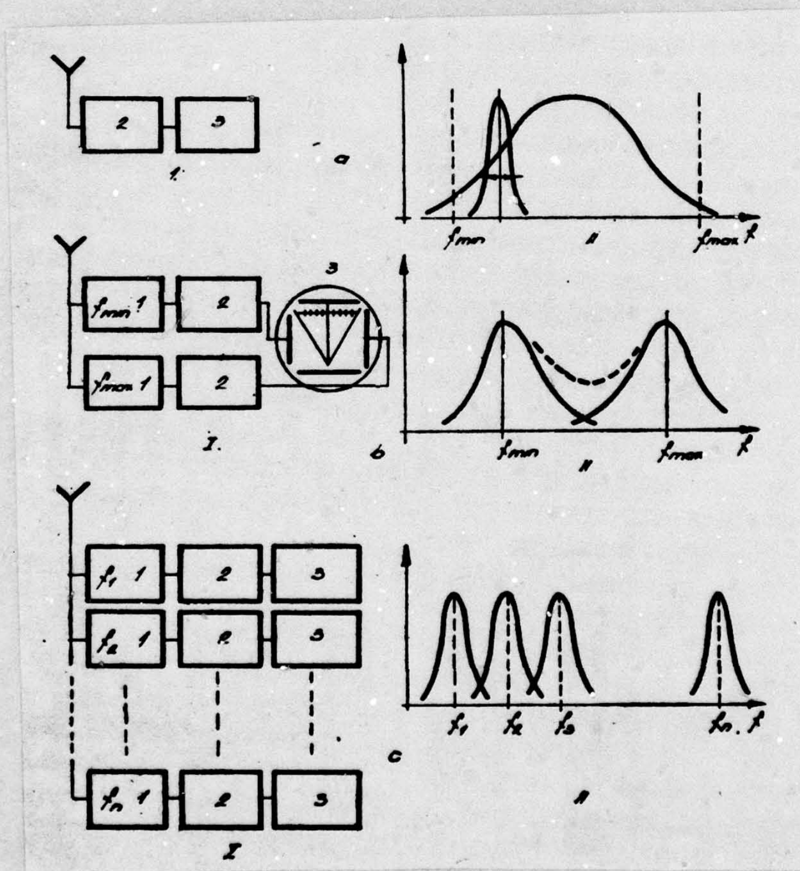


Figure 5.2.

Principal block schematics of receivers with direct amplification (I) and their frequency characteristics (II) - a - single-channel version, b - two-channel version, c - multi-channel version: 1 - filter, 2 - receiver; 3 - indicator.

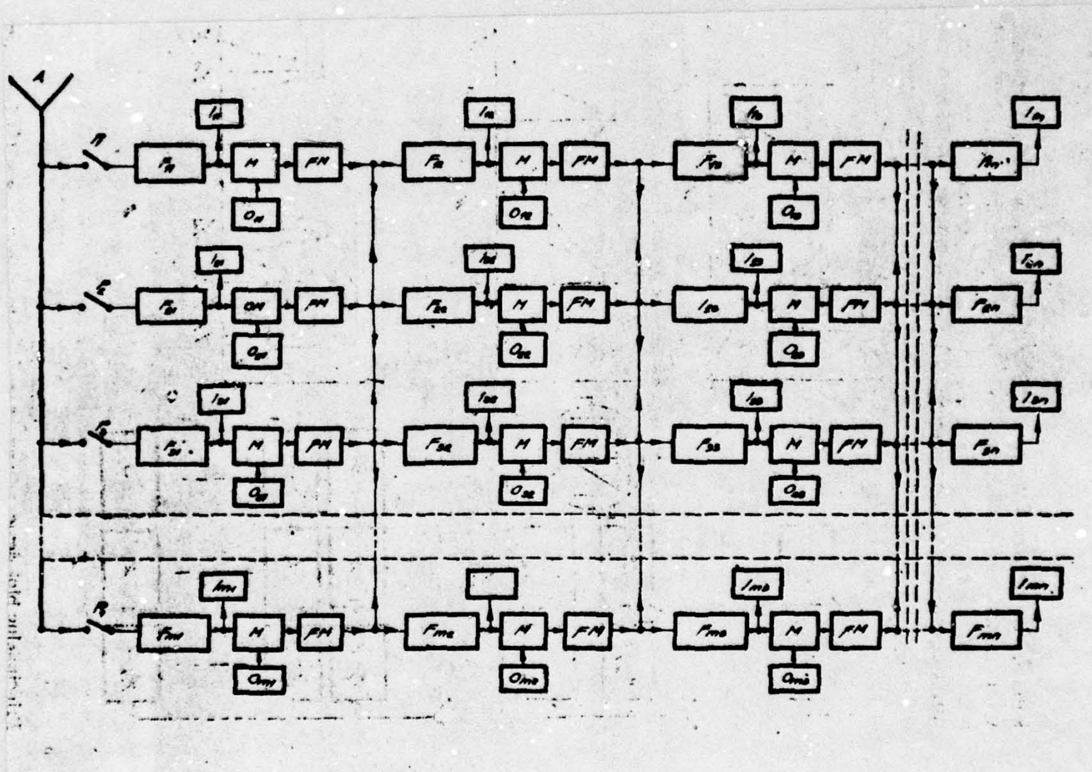


Figure 5.3.

In-principle block schematic of a multi-channel cokbined receiver. F - range filters, M - degrees of mixing, O - oscillators, P - Switch, FM - permeable filters resulting from mixing, I-indicators of signal present.

The development of technology of integrated components, microwav semiconductor oscillators, and bandlike wave-conducting elements **makes** this type of installations all the more promising.

The present-day multi-channel reception can be accomplished also by the use of a multi-channel combined receiver, which in its operation makes use of the possibilities of the receiver with direct amplification, combined by mixing and successive division of individual frequency ranges. The in-principle schematic is shown in Figure 5.3, whereas Figure 5.4 shows the transporting of frequency ranges for the combination case of three outputs and four transpositions.

Since the receiver is by design similar to mathematical form of the matrix, it can conditionally be called a matrix receiver and the notations customary for the matrices can be used. This receiver is composed of m rows-channels and n columns - divisors of frequency ranges.

In the first column the total frequency range of the matrix receiver is divided into m subranges

$$\Delta f_1 = \frac{f_{max} - f_{min}}{m} \qquad (5.3)$$

The boundary frequency of the subranges, and hence also of output filters are

$$\left.\begin{aligned}
&f_{11d} = f_{min} \\
&f_{11g} = f_{11d} + \Delta f_1 = f_{min} + \Delta f_1 \\
&f_{21d} = f_{11d} + \Delta f_1 = f_{min} + \Delta f_1 \\
&f_{21g} = f_{21d} + \Delta f_1 = f_{min} + 2\Delta f_1 \\
&\vdots \qquad\quad \vdots \qquad\quad \vdots \qquad\quad \vdots \\
&f_{m1d} = f_{(m-1)1d} + \Delta f_1 = f_{min} + (m-1)\Delta f_1 \\
&f_{m1g} = f_{m1d} + \Delta f_1 = f_{min} + m\Delta f_1 = f_{max}
\end{aligned}\right\} \qquad (5.4)$$

The frequencies of the oscillators in the first column are selected such that a uniform and unequivocal transposition of all rows (arrays) is obtained at a lower frequency

$$\left.\begin{array}{l} f_{o,11} = f_{11g} + \frac{\Delta f_1}{m} \\ \vdots \qquad \vdots \\ f_{o,m1} = f_{max} + \frac{\Delta f_1}{m} \end{array}\right\} \tag{5.5}$$

The result of the mixing is in all the rows on the basis of equations 5.4 and 5.5 equal. The lower and the upper boundary frequencies along the rows (arrays) are equal and amount to:

Lower boundary frequency of the subrange

$$f_{1d} = f_{o,11} - f_{11d} = f_{o,m1} - f_{md}\ f_1 + \frac{\Delta f_1}{m} \tag{5.6}$$

Upper boundary frequency of the subrange is:

$$f_{1g} = f_{o,11} - f_{11g} = f_{o,m1} - f_{m1g} = \frac{\Delta f_1}{m} \tag{5.7}$$

The frequency range obtained amounts to

$$\Delta f_1 = f_{1g} - f_{1d} = \Delta f_1. \tag{5.8}$$

In the second column the procedure from the first column is repeated, only that now instead of the frequency range of the receiver being divided into subranges, the newly obtained frequency range from equations (5.6) to (5.8) is. The width of the frequency subrange of the second column is

$$\Delta f_2 = \frac{\Delta f_1}{m} \tag{5.9}$$

the boundary frequencies of the subrange and hence also the boundary frequencies of the filter are given by

$$\left.\begin{array}{l} f_{12d} = \frac{\Delta f_1}{m} \\ f_{12g} = \frac{\Delta f_1}{m} + \Delta f_2 \\ f_{22d} = \frac{\Delta f_1}{m} + \Delta f_2 \\ f_{22g} = \frac{\Delta f_1}{m} + 2\Delta f_2 \\ \vdots \qquad \vdots \end{array}\right\} \tag{5.10}$$

$$\left.\begin{aligned} f_{m2d} &= \frac{\Delta f_1}{m} + (m-1)\,\Delta f_2 \\ f_{m2g} &= \frac{\Delta f_1}{m} + m\,\Delta f_2 \end{aligned}\right| \tag{5.10}$$

The frequencies of the oscillators are obtained similarly to the first column by (5.5)

$$\begin{aligned} f_{o,12} &= f_{21g} + \frac{\Delta f_2}{m} = \frac{\Delta f_1}{m} + \Delta f_2 + \frac{\Delta f_2}{m} \\ &\vdots \qquad\qquad\qquad \vdots \\ f_{o,m2} &= f_{m2g} + \frac{\Delta f_2}{m} = \frac{\Delta f_1}{m} + m\Delta f_2 + \frac{\Delta f_2}{m} \end{aligned} \tag{5.11}$$

The result of the mixing is again equal in all the rows.

The lower boundary frequency of the subrange amounts to

$$f_{2d} = f_{o12} - f_{12d} = f_{om2} - f_{m2d} = \left(1 + \frac{1}{m}\right)\Delta f_2 \tag{5.12}$$

The upper boundary frequency of the subrange amounts to

$$f_{2g} = f_{o12} - f_{12g} = f_{om2} - f_{m2g} = \frac{\Delta f_2}{m} \tag{5.13}$$

The frequency range obtained is

$$\Delta f'_2 = f_{2g} - f_{2d} = \Delta f_2 \tag{5.14}$$

For the third column this process is repeated.

Just like it is through columns that the division of frequency subranges occurs, so it is on their number that the accuracy of showing the frequency depends.

$$\delta = \frac{f_{max} - f_{min}}{2 \cdot m^n} \tag{5.15}$$

where: δ = required accuracy in frequency determination,

Δf_1 = first frequency subrange,

m = number of rows,

n = number of columns.

The characteristic data, as well as the permeable ranges of the filters and the oscillator frequencies are listed in Table 5.1.

row \ column	1	2	n
1	$f_d = f_{min}$ $f_g = f_{min} + \Delta f_1$ $f_o = f_{min} + \Delta f_1\left(1+\frac{1}{m}\right)$	$f_d = \Delta f_2$ $f_g = 2\Delta f_2$ $f_o = \Delta f_2\left(2+\frac{1}{m}\right)$	$f_d = \frac{1}{m}\Delta f_n$ $f_g = \frac{2}{m}\Delta f_n$ $f_o = \left(\frac{2}{m}+\frac{1}{m^2}\right)\Delta f_n$
2	$f_d = f_{min} + \Delta f_1$ $f_g = f_{min} + 2\Delta f_1$ $f_o = f_{min} + \Delta f_1\left(2+\frac{1}{m}\right)$	$f_d = 2\Delta f_2$ $f_g = 3\Delta f_2$ $f_o = \Delta f_2\left(3+\frac{1}{m}\right)$	$f_d = \frac{2}{m}\Delta f_{(n-1)}$ $f_g = \frac{3}{m}\Delta f_{(n-1)}$ $f_o = \left(\frac{3}{m}+\frac{1}{m^2}\right)\Delta f_{(n-1)}$
m	$f_d = f_{min} + (m-1)\Delta f_1$ . . . $f_g = f_{max}$ $f_o + f_{max} + \frac{\Delta f_1}{m}$	$f_d = m\Delta f_2$ $f_g = (m+1)\Delta f_2$ $f_o = \Delta f_2\left(1+m+\frac{1}{m}\right)$	$f_d = m\Delta f_n$ $f_g = (m+1)\Delta f_n$ $f_o = \Delta f_n\left(1+m+\frac{1}{m}\right)$
	$\Delta f_1 = \frac{f_{max} - f_{min}}{m}$	$\Delta f_2 = \frac{\Delta f_1}{m}$	$\Delta f_n = \frac{\Delta f(n-1)}{m}$

Table 5.1. Characteristic data of "matrix" receiver.

The advantage of the "matrix" receiver consists in that for the same accuracy in the frequency a much smaller number of channels is necessary than is the case for a multi-channel system. This is seen from the following example.

It is desired to cover the frequency range from 2,700 MHz to 10,800 MHz by a reconnaissance receiver with an accuracy of $\delta =$ $= \pm$ 16.5 MHz.

In case of a multi-channel receiver one must use for the required accuracy

$$n = \frac{10800-2700}{2 \cdot 16{,}5} = 246 \text{ channels.}$$

If we utilize the matrix receiver, with same accuracy requirements, we find that 3 rows and 5 columns are sufficient. All in all 3x5 = 15 filters are needed in contrast to 246 in case of a multi-channel receiver, which is a distinct advantage. In addition, it is easier to construct keen filters at low frequencies than at high ones.

The characteristic frequencies for the given example are given in Table 5.2.

To the extent that on the input of the matrix receiver arrives a signal of frequency 3,500 MHz, the indicators I_{11}, I_{32}, I_{33}, I_{14}, I_{15} (designated in Table 5.2 by X) are activated.

The frequency diagram of this transposition is given in Fig. 5.4.

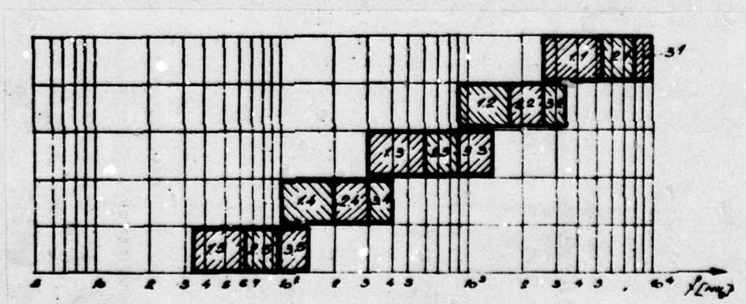


Figure 5.4.

Frequency transposition diagram of the derived example.

Matrix receivers do not only have the said advantages, but also have a serious shortcoming: Selection is impossible if several signals simultaneously arrive at the input channels-rows. This can

be avoided by the introduction of special components. as well as row and column selection. One of the simplest ways of correction is the time gradual inclusion of input levels (switch P_1—P_m in Fig. 5.3). Then the matrix receiver transforms into a "pyramidal" one, with the input level at the top of the pyramid.

b) <u>Superheterodyne receivers.</u> - With respect to receivers with direct amplification they have by several times higher sensitivity and selectivity, the width of their permeable range can be altered, and they can be attuned over a wide frequency range. Their principal shortcoming is, besides their complexity, in their design, whereby

	1	2	3	4	5
1	f_d = 2700 MHz × f_g = 5400 MHz f_o = 6300 MHz	f_d = 900 MHz f_g = 1800 MHz f_o = 2100 MHz	f_d = 300 MHz f_g = 600 MHz f_o = 700 MHz	f_d = 100 MHz × f_g = 200 MHz f_o = 233,3 MHz	f_d = 33,3 MHz × f_g = 66,6 MHz
2	f_d = 5400 MHz f_g = 8100 MHz f_o = 9000 MHz	f_d = 1800 MHz f_g = 2700 MHz f_o = 3000 MHz	f_d = 600 MHz f_g = 900 MHz f_o = 1000 MHz	f_d = 200 MHz f_g = 300 MHz f_o = 333,3 MHz	f_d = 66,6 MHz f_g = 99,9 MHz
3	f_d = 8100 MHz f_g = 10800 MHz f_o = 11700 MHz	f_d = 2700 MHz × f_g = 3600 MHz f_o = 3900 MHz	f_d = 900 MHz × f_g = 1200 MHz f_o = 1500 MHz	f_d = 300 MHz f_g = 400 MHz f_o = 433,3 MHz	f_d = 99,9 MHz f_g = 133,3 MHz

Table 5.2. Characteristic values for the derived example.

relatively much time is required for the attunement along the frequency range, which considerably reduces the possibility of detection, in particular in case of short-term signals. One must not forget here that the reception of the reconnoitered transmitting signal will occur only if at the same instant the antennas of the

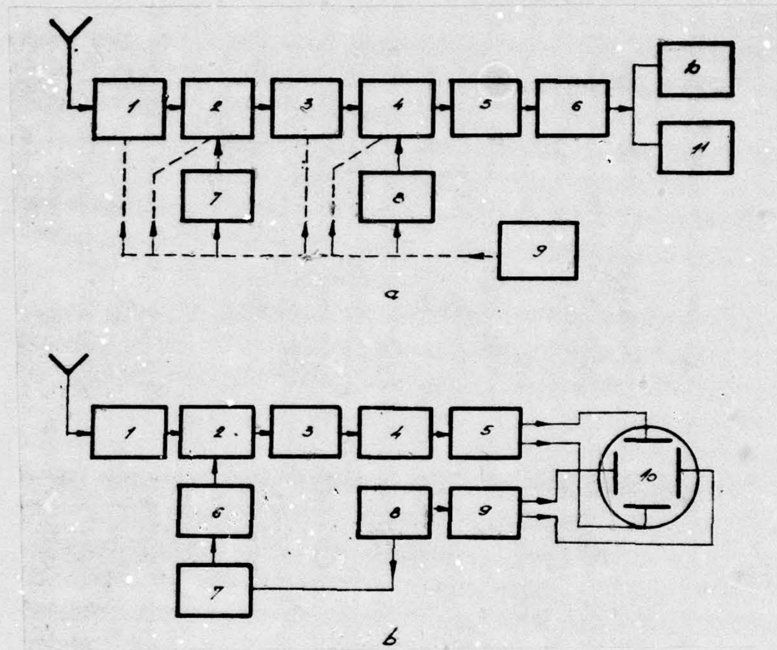


Figure 5.5.

In-principle block schematics of superheterodyne receivers: a) with motor or manual attunement drive: 1-VF amplifier, 2 - I mixer, 3 - VF amplifier, 4 - II mixer, 5 - MF amplifier, 6 - detector, 7 - oscillator of I mixing, 8 - oscillator of II mixing, 9 - component of manual or motor attunement drive, 10 - NF amplifier with aural indicator, 11 - NF amplifier with visual indicator; b) panoramic receiver: 1 - VF wide-band amplifier, 2 - mixing level, 3 - MF amplifier, 4 - detector, 5 - NF amplifier, 6 - mixing oscillator, 7 - reactance level, 8 - generator of indented tension, 9 - two-phase amplifier, 10 - indicator.

transmitting and the reconnaissance receiving installation are aimed at one another and if then the reconnaissance receiver is attuned to the transmitter frequency. In principle, two types of receivers are used:

- superheterodyne receiver with single or double mixing, manual or motor drive of the elements for attunement and aural or visial indication (Fig. 5.5a), and

- superheterodyne receiver with electronic searching of the range and the visual and aural indication of the received signal. This type of receivers is, due to the visual indication, called also panoramic receiver (Fig. 5.5b).

c) Search methods by frequency. - As has been mentioned in the preceding point, the successful indexing of the signal depends on the manner of frequency search which is used by the electronic reconnaissance receiver. This is particularly so for the installation which has a directed radiation diagram and which during the operating time changes its position in space (radars, guidance systems, directed communications systems, etc.).

In principle, two types of searching are distinguished, the slow and the fast (Fig. 5.6).

The mutual encounter between antenna beams of the reconnaissance receiver and the reconnoitered transmitter occurs in time (Tosvet). [= T_{illum}]. If either of the antenna beams or both of them rotate, then their encounter repeats itself in time (Tpon) [=T_{rep}].

Pre-attunement of the receiver is done between the extreme frequencies (f_{min} and f_{max}) with the width of the permeable range of the receiver (Δf_{prij}) [=Δf_{rec}]. The time necessary for the pre-attunement of the receiver from one to another boundary frequency for rapid searching is shorter (T'_{pret}) [T'_{search}] and for slow

searching it is bnger (T_{pret}) [$\approx T_{serach}$].

The condition for fast searching by frequency is

$$T_{imp} \leqslant T'_{pret} \leqslant T_{osvet} \tag{5.16}$$

where: T_{imp} = time interval between two pulses;

T'_{pret} = time for a single pre-attunement of the receiver;

T_{osvet} = time of encounter of antenna beams.

In case of the pulse transmitter, in particular the kind that changes its frequency from pulse to pulse unequally, the (5.16) assumes the form

$$\tau \leqslant T'_{pret} \leqslant T_{imp} \tag{5.17}$$

where τ is the duration of an individual pulse.

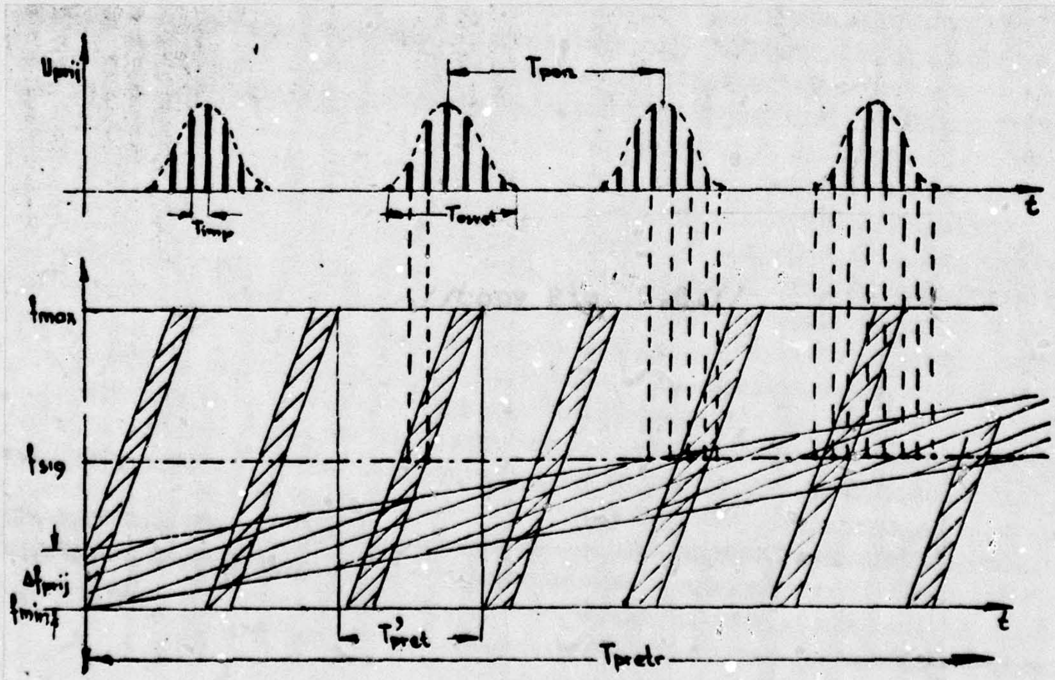


Figure 5.6.

Principle of fast and slow searching by frequency.

If nonequality (5.17) becomes equality from the left side, then each pulse shall be recorded even though it changes the frequency. In case of fast searching we have

$$T'_{prelr} \lessdot T_{osvet} \qquad (5.17)$$

and no encounter by frequency occurs at each illumination time. A favorable ratio of the magnitudes is given by the relation

$$T_{pret} \leqslant \frac{f_{max} - f_{min}}{\Delta f_{prij}} \cdot T_{pos} \qquad (5.18)$$

where: f_{min}, f_{max} = boundary frequencies of the receiver

Δf_{prij} = width of the permeable range of the receiver.

5.2.2. DIRECTION DETERMINATION

In addition to frequency determination of the reconnoitered electronic device the as accurate as possible determination of its position is also important. The position can be determined by goniometric methods, which means that one first determines from one or more known points the directions to the reconnoitered electronic device. The accuracy of the determined position will be the higher the narrower are the antenna beams used for the searching, and if the intersection point is determined from more than two directions. If, however, only two directions are available, then the accuracy is highest when they intersect under an angle of 90° (Fig. 5.7 a, b, c, d).

Each determination of individual directions is a two-stage operation, namely consisting of:

- adjustment of the receiver of the installation for electronic reconnaissance to the frequency of the source of electromagnetic radiation (Point 5.2.1, p. 100 of original copy)(p. 115 of translation).

- Arrangement of the received signals to various directions of the antenna of the receiver installations and on the basis of this the

determination of the direction.

Both operations must - depending on the type of the observed electromagnetic radiation source - be executed within a very short time (order of magnitude - millisecond).

The received signals can for the sake of direction determination be arranged by amplitude or phase of the received signal. The amplitudes can be determined by the maximum method, the minimum method, and the comparison method.

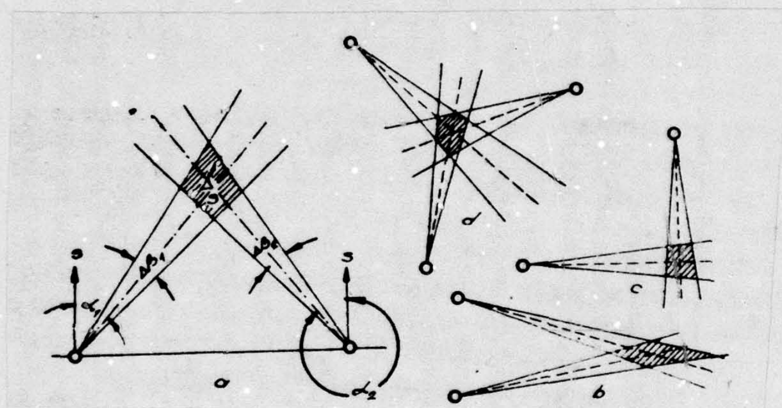


Figure 5.7.

a - Goniometrization of electromagnetic radiation source (α_1 , α_2 = azimuthal angles of radiation source, $\Delta\beta_1$, $\Delta\beta_2$ = errors in the determination of the direction, S = surface on which the radiation source is located; b -the worst possible goniometrization method using two goniometers - the S surface is the largest; c - the best goniometrization method using two goniometers; d - optimal goniometrization method using 3 goniometers under an angle of 120°

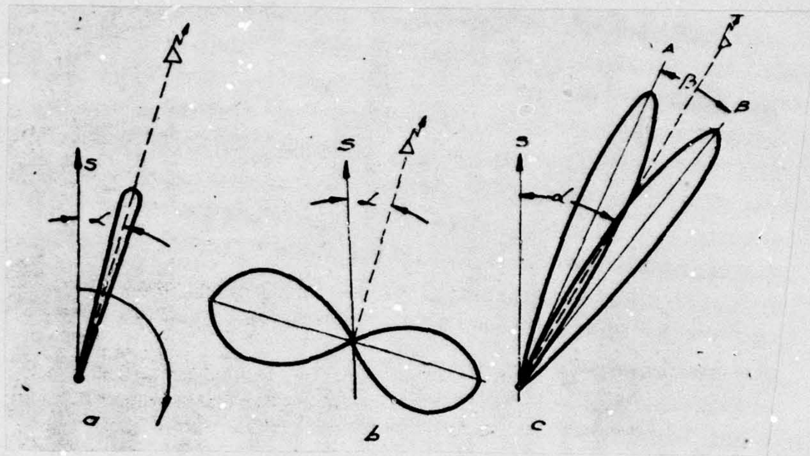


Figure 5.8.

Methods of direction determination by amplitude of the received signal: a - maximum method, b - minimummethod, c - comparison method

a) Determination of the direction by amplitude of the received signal. - The maximum method: If the sufficiently narrow antenna beam rotates around the azimuth, then the angle between the direction of the maximal signal and the north (α) is the azimuth of the device reconnoitered (Fig. 5.8a).

The maximum method is being employed with rather good success in the ultra-short waves (USW) region, since good directionality can be obtained by antennas of relatively small dimensions. The antenna has a very directed beam and therefore a high amplification of it can receive also weaker signals from a greated distance. The accuracy of the direction determined is due to the width of the antenna beam.

The minimum method can be used in all wave regions. The only thing that is required is that the antenna diagram contains one or at most two reception minima (Fig. 5.8b). In the majority of the cases antennas are used having the reception diagram in the form of an eight.

Although the intrinsic noise of the receiver precludes greater accuracy in the determination of the direction of minimal signals, this method is used to attain a greater accuracy than is attainable by the maximum method and in the ultra-short wave region it amounts to 1^{o} to 3^{o}. Its shortcoming is in that much time is required for turning the antenna for the purpose of finding the minimum.

The comparison method: The comparison method came to be based on the advantages of the two methods above (higher sensitivity - the maximum method, higher accuracy - the minimum method)(Fig. 5.8c). For the operation two equal antenna beams A and B with known mutual angular interval β is used. When the receiving signals from beam A are equal to the signals from beam B, the antenna system is turned toward the direction of the radiation source. This will happen when the direction to the radiation source is is the symmetry line of angle β.

In case of amplitudinal methods the antenna of the installation for electronic reconnaissance must search in space. In case of the source of electromagnetic radiation with resting radiation diagram the rate of the searching does not represent any particular problem. However, in the case of turning of either one of the beams (example of reconnaissance of radar installations) the selection of the turning rate of the antenna of the reconnaissance installation is one of the essential factors for successful reconnaissance. Reconnaissance is possible only when the antenna beams are aimed at each other (Fig. 5.9 line R—I).

The turning of the antenna of the reconnaissance installation can be either fast or slow. In case of slow turning the antenna of the reconnaissance installation turns for the width of its beam (angle β_i) in time which is necessary for the antenna of the reconnoitered radar installation to make one single turn. By such a way of turning the antenna of the reconnaissance installation it surely happens in one of its turns from 360° that the instant arrives when the antenna beams are aimed at one another. The time required for a single turn of the antenna of the reconnaissance installation

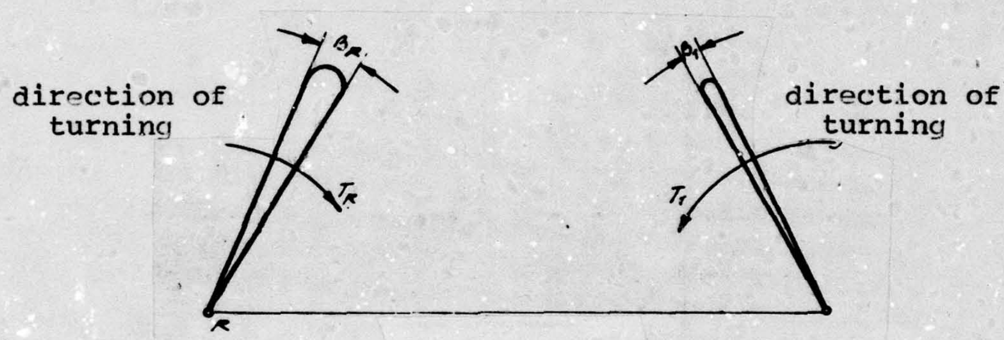


Figure ,5.9.

Detection conditions for two mobile antenna beams: R - beam from radar installation, I - beam from reconnaissance installation

must satisfy the condition

$$T_i \geqslant \frac{2\pi}{\beta_i} \cdot T_R = \frac{360^\circ}{\beta_i\,[^\circ]} T_R \qquad (5.19)$$

where T_i and T_R are the times necessary for a single turn of the antenna of the station for the detection, or radar, respectively.

In case of fast turning of the antenna of the reconnaissance installation it turns very fast and makes one turn in a time which

is not greater than the time necessary for one single turn of the antenna of the reconnaissance installation to turn the distance equal the width of its beam (angle β_R). The time necessary for a single turn of the antenna of the reconnaissance installation must then satisfy the condition

$$T_1 \leqslant \frac{\beta_R}{2\pi} \cdot T_R = \frac{\beta_R\,[^\circ]}{360^\circ} \cdot T_R \quad [\text{sec}] \tag{5.20}$$

Which of the cited ways shall be used in the reconnaissance of a certain installation depends mainly on the method of analysis of the signal and the time which is necessary for the analysis.

b) Automatic determination of the direction. - For automatic determination of the direction a two-channel goniometer (Fig. 5.10) is used the most frequently, which includes two immobile antennas,

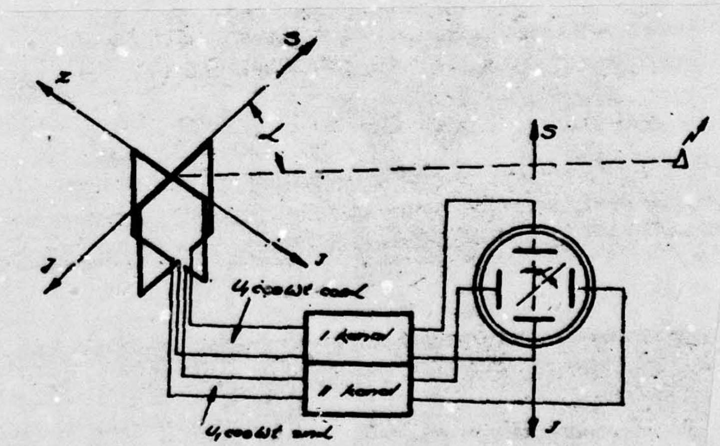


Figure 5.10.

Two-channel automatic goniometer with immobile antennas

two identical receiving channels, and an oscilloscopic direction indicator. The signal from the reconnoitered source of electromagnetic radiation is received simultaneously by two antennas positioned at

a right angle with respect to one another. Their orientation is in accordance with the countries of the world. The signal received from the antenna is

$$\left.\begin{aligned} u_1 &= U\cos\omega t\cdot\cos\alpha \\ u_2 &= U\cos\omega t\cdot\sin\alpha \end{aligned}\right\} \qquad (5.21)$$

where angle α is the angle between the north and the direction to the radiation source. After each amplification (A) the signals are simultaneously led into both channels on the deviation system of the cathode tube. There they produce such a deviation of the electronic ray that a line appears on the screen which - with respect to the vertical - is oriented toward the north, and occupies an angle α_0

$$\alpha_0 = \operatorname{arctg}\frac{u_2 A}{u_1 A} = \operatorname{arctg}(\operatorname{tg}\alpha) = \alpha \qquad (5.22)$$

From the relationship (5.22) it can be seen that angle (α_0) on the indicator ideally reproduces angle (α) between the north and the direction to the radiation source.

5.2.3. SPACE SEARCH METHODS

Installations for electronic reconnaissance can be mounted onto a vehicle, a floating facility, or an aircraft. Due to small heights of the antennas which can be attained on vehicles and floating installations, the detection distances are also small, which is why these devices are used mostly for near reconnaissance (along the coast, border, front line, etc.) On the aircraft, the antennas of the receiving installation attain greater heights and consequently a greater reconnaissance range is attained also (see point 5.3, p. 136 of original copy, p. 138 of translation). The usual space search methods are shown in Fig. 5.11.

The width of the searched space under the aircraft is for the case of Fig. 5.11a equal to

$$a=2h\,\mathrm{tg}\frac{\theta}{2} \tag{5.23}$$

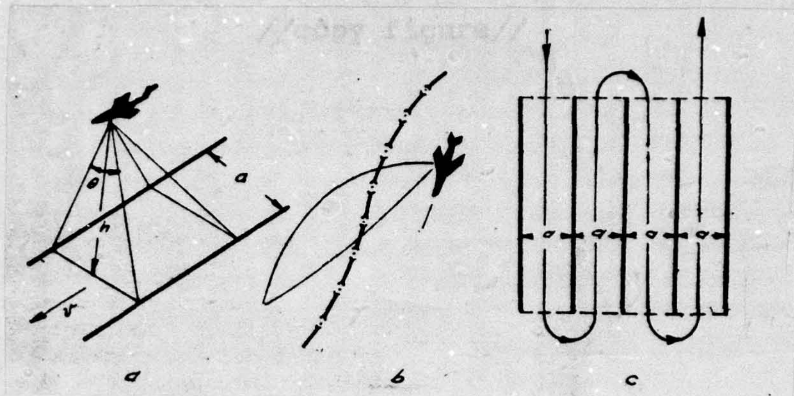


Figure 5.11.

Methods of airborne reconnaissance: a - under the aircraft, b - sideways from the aircraft, c - searching of larger spatial complex

and this is at the same time also the interval between two neighboring flights for the search method from Fig. 5.11c.

As was seen from Point 5.2.2. (p. 112 of original copy; p. 127 of translation), the geographical position of the radiation source on the terrain is determined from the intersection of at least two directions. In case that reconnaissance installation is mounted on a vehicle or floating object, the determination of the intersection is easier and more accurate because the coordinates of the start of the direction are known. If the reconnaissance installation is mounted onto an airplane, the parameters designated in Fig. 5.12 must be known in order to be able to determine the geographical position of the radiation source.

The surface S which goniometers determine as the geographical site

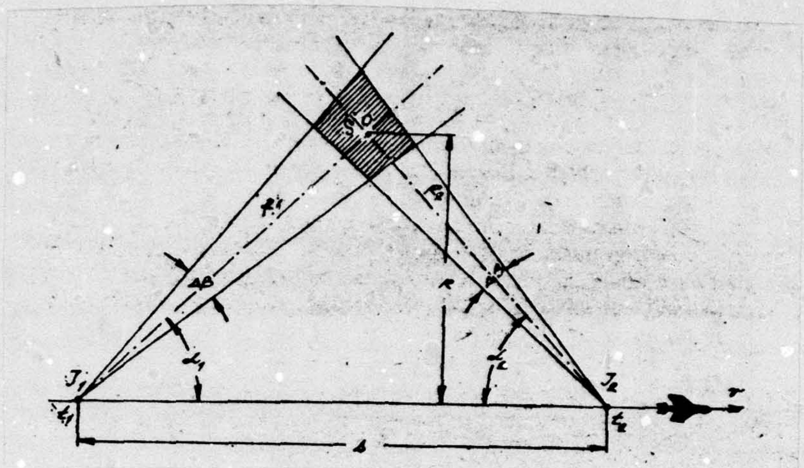


Figure 5.12. Geometry of the determination of the geographical position of the ground radiation source from an aircraft:

I_1 - position of the aircraft at first measurement,

I_2 - position of the aircraft at second measurement,

t_1 - time in which the first measurement was performed,

t_2 - time in which the second measurement was performed,

S - path traversed by the aircraft between the first and the second measurement,

$\Delta\beta$ - antenna beam width of the reconnaissance installation,

v - aircraft speed,

S - surface on which the radiation source is located,

R - smallest distance between the observation object and flight itinerary.

for the radiation source we also call the indefiniteness surface (since every point on it is of equal order and may be the position of the reconnoitered device). The indefiniteness surface is equal to (designations on Fig. 5.12)

$$S = \frac{4 \cdot R^2 \left(\mathrm{tg}\,\frac{\Delta\beta}{2}\right)^2}{\sin(\alpha_1+\alpha_2)\sin\alpha_1\sin\alpha_2} \qquad (5.34)$$

and it is minimal if the angles $\alpha_1 = \alpha_2 = 60^\circ$ and is equal to

$$S_{\min} = \frac{4R^2\,\mathrm{tg}^2\,\frac{\Delta\beta}{2}}{(0,866)^3} = 6,2R^2\,\mathrm{tg}^2\,\frac{\Delta\beta}{2} \qquad (5.35)$$

Thus, for instance, an airplane on which two antennas are mounted having beam width $\Delta\beta = 4^\circ$ under the angle $\alpha_1 = \alpha_2 = 60^\circ$, the radiation source is obtained at a distance R = 100 km, the indefiniteness surface being S = 750.2 km^2.

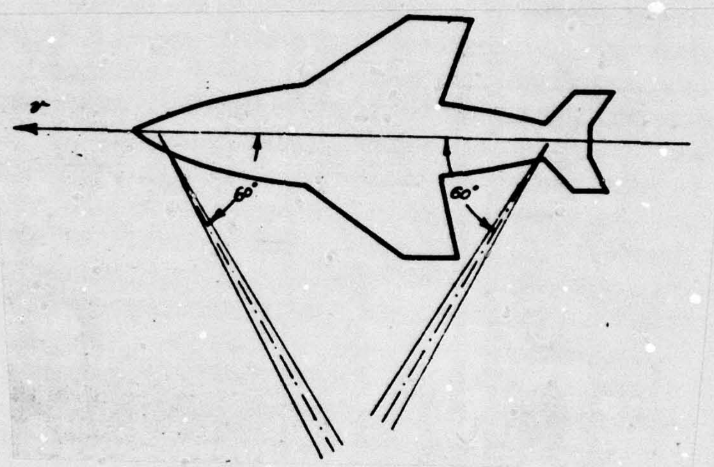


Figure 5.13.

Mounting of the antenna for the determination of the geographical position for the radiation source on the airplane.

From equation (5.35) it is seen that using an airplane one can easiest and most accurately determine the geographical position of the radiation source by using two immobile antennas mounted on the aircraft (Fig. 5.13) and this in such a way that they subtend with the airplane axis an angle of 60°. The indefiniteness surface S will in this case depend only on the width of the antenna beam of the receiving antenna.

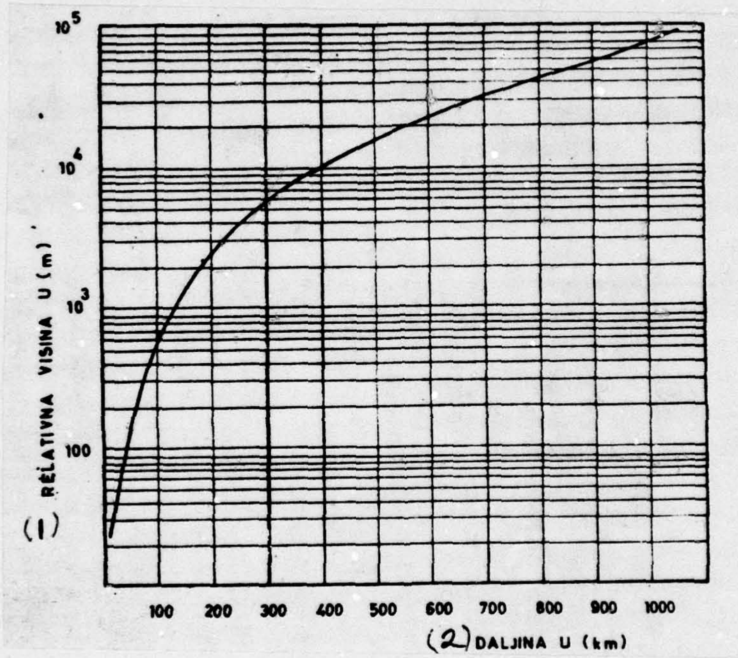


Figure 5.14. Dependence of maximum distance determined on relative height between antenna location and reconnaissance receiver with rectilinear propagation without refraction.

1 - Rel. height; 2 - Distance U (km)

5.3. DISTANCE OF ELECTRONIC RECONNAISSANCE

The distance at which electronic reconnaissance of the radiation source can be achieved depends, in principle, on:

- propagation conditions of electromagnetic waves on the source--device relation;

- parameters of the installation for electronic reconnaissance (sensitivity of the receiver, antenna amplification, intrinsic noise level), and

- parameters of the radiation source (radiated power, antenna amplification, and similar).

Due to rectilinear propagation of VSW ~~VKT~~ and USW ~~UKT~~ (i.e. both meaning ultra-short waves)* of electromagnetic waves the largest possible distance that can be detected is determined by the height of the antennas. For normal refraction conditions this distance can be calculated from

$$R_0 = 4{,}13\left(\sqrt{h_1} + \sqrt{h_2}\right) \tag{5.36}$$

where h_1 and h_2 = above sea level heights of the antennas in m,

R_0 = distance in km.

For long, medium, and short wave regions this distance is larger and depends on the nature of their propagation (superficial or spatial wave).

If the height is expressed by the relative height, then one can calculate the diagram of the maximal detection distances depending on the relative heights (as given in Fig. 5.14). From this diagram it can be seen that with increased relative height the detection

---

* VKT = vrlo kratki talasi = ultra-short waves = (lit.) very short waves.
UKT = ultra-kratki talasi = ultra-short waves.
(Translator's Note)

distance increases. For this reason the reconnaissance installations are also mounted on airplanes or on satellites. In case of ship installations, the antennas are mounted at as high as possible heights, and the highest possible position is always selected for reconnaissance installations mounted on vehicles.

The receivers of the electronic reconnaissance installation are usually very sensitive, for the purpose so that the actual detection distance would be as large as possible.

The detection distance for installations with rectilinear radiation of electromagnetic waves is also in free space equal to

$$R_o = \sqrt{\frac{P_{max} \cdot G \cdot G_p \cdot \lambda^2 \cdot \gamma \cdot \eta}{16 \cdot \pi^2 \cdot n \cdot P_{prij}}} \tag{5.37}$$

where: P_{max} = maximal radiated power of the installation which is being reconnoitered; G = amplification coefficient of the antenna of the installation which is being reconnoitered; G_p = amplification coefficient of the reconnaissance receiver antenna; γ = coefficient which envelops non-overlapping in polarizations of both antennas - generally γ = 0.5; η = use factor of the received signal in the reconnaissance receiver, generally η = 0.5; P_{prij} = minimal sensitivity of the reconnaissance receiver, however equal to its noise level; n = increase coefficient of the useful signal above the receiver noise level necessary for safe operation of the analyzer.

Equation (5.36) does not take into account attenuations in the atmosphere. To the extent that it is desired that it be taken into consideration due to more accurate calculations, one must take from the diagram of Figs. 7.11 and 7.12 the attenuation value as a function of the precipitation intensity and in that way correct equation (5.37). The corrected form is

$$R = \sqrt{\frac{P_{max} \cdot G \cdot G_p \cdot \lambda^2 \cdot \gamma \cdot \eta}{16 \cdot \pi^2 \cdot n \cdot P_{prij}}} \cdot e^{-\frac{\beta R_o}{20}} \tag{5.38}$$

where the designations are the same as in equation (5.36) and β = attenuation in (db/km).

Besides the electromagnetic radiation source which is used by the antennas, it is also possible to reconnoiter installations which are in the receiving state and which have their transmitters attached to artificial antennas. The reconnaissance of such powerful transmitters is especially easy, such as are the radar, navigational, or receiving systems for missile guidance, in particular since in their receiving period they always operate on artificial antennas. The reason for this useless radiation are imperfect artificial antennas, poor connections, and non-adjustments in the high-frequency tracts. The power of nondesirable radiation may be significant and it fluctuates from 0.1 to several percent of the maximal one (for radar of output power of 14W, the useless radiation can be as high as 10 KW). The range equation (5.37) for this case acquires the form

$$R = \sqrt{\frac{P \cdot G_{p} \cdot \lambda^{2} \cdot \gamma \cdot \eta}{16 \cdot \pi^{2} \cdot n \cdot P_{prs}}} \qquad (5.39)$$

where P = power of parasitic radiation; the rest of the designations (symbols) are as in (5.37).

VI ELECTRONIC COUNTERMEASURES AGAINST MEANS OF COMMUNICATIONS

In contemporary war actions the use of all kinds of means to maintain communications is great and it has an obvious tendency to increase. Since successful direction and unfolding of military actions in general greatly depends on their effectiveness, the enemy side will tenaceously strive to affect the enemy system of communications.

Countermeasures to communications systems are mainly the following:

reconnaissance and radio goniometration of means of communication - Using electronic reconnaissance methods the frequencies of output power, location, interconnections, and characteristic properties of of the means of communications. Under the characteristic properties are understood the positive sign or or nickname, voice color or nature of manipulation by the operator, kind of modulation and its level, additional noise characteristics for the surroundings of the means of communications, etc.,

monitoring - By constant monitoring of the operation of uncovered means of communications valuable data can be obtained regarding the enemy intentions. Besides reconnaissance and deception, monitoring is one of the most used countermeasures against these means. Because of this, the methods and means for coding and decoding of the communications are daily being improved;

deception - By throwing into the enemy communications system and by broadcasting various misinformation, such as, false orders and directives, confusion is introduced into the enemy organization.

In addition, by setting up false radio stations or communications systems and by organization of their activity the actual actions of own forces can be masked and the enemy is brought into a perplexed state in regard to their intentions;

active jamming - understood here is the creation at the reception site of a field of such strength that the reception of the participant transmitting signal if not made totally impossible it is at least to a high degree made difficult. Active jamming demands the application of large emitting power which is why it is also called the application of "brute force". Various methods are being employed against the various means of communications, which differ by the method of modulation, by the magnitude of the carrying wave and, finally, by the necessary field strength at the reception site.

Active jamming of means of communications is generally organized in situations in which reliable communications are necessary (such as in grouping of the forces, organization of joint actions, after inflicting a strike by KM, upon transfer of KM, when guiding aircarft toward the target, and similar).

Since means of communications during the operation utilize rectilinear propagation of electromagnetic waves, the superficial and the spatial wave, the active jamming must also utilize these same ways of propagation.

Installations for active jamming are mounted on vehicles, aircraft, or ships, depending on their characteristics and methods of application.

In the following chapters the active jamming is dealt with since it is of technological nature, while monitoring and deception are actions of a tactical nature.

6.1. THE NECESSARY POWER AND RANGE OF AN ACTIVE JAMMER

For jamming to be effective, the power of the jamming signal at the output of the jammed received must attain such a value that it effectively exceeds the simultaneously received useful (intelligent) signals. Since the magnitude of the jamming signal in case of means of communications depends on the nature of emission, modulation, and directionality, the usual practice is to introduce the jamming factor γ as the minimal ratio of the input powers for effective jamming of the installation. The jamming factor is

$$\gamma \leq \frac{P_{prij\cdot om}}{P_{prij\cdot sig}} \tag{6.1}$$

where: $P_{prij\cdot om}$ = power of jamming signal at reception site

$P_{prij\cdot sig}$ = power of useful signal at reception site.

The jamming factor γ is determined experimentally, especially for each type of modulation and propagation. By it is determined by how much the jamming signal must be higher than the useful (intelligent) signal at the reception site.

Since the attenuation of the signal on the trace is affected also by the nature of propagation, one must know this attenuation for the sake of organization of successful jamming. In Fig. 6.1 are shown the measured attenuation values with respect to the nature of the propagation for the frequency of 40 MHz. Curve 1 shows the theoretical value of the attenuation in free space, where for all frequencies it increases by 6 db per octave. (Under octave is understood a twofold distance: for 10 km the octave is 20 km). Curve 1 is only considered if both the jammer and the jammed are present in the air. Curve 2 with attenuation of 12 db per octave corresponds to the propagation above an ideally even earth's surface (sea surface, lake surface, large flatlands, and similar). Curve 3 with attenuation of 15 db per

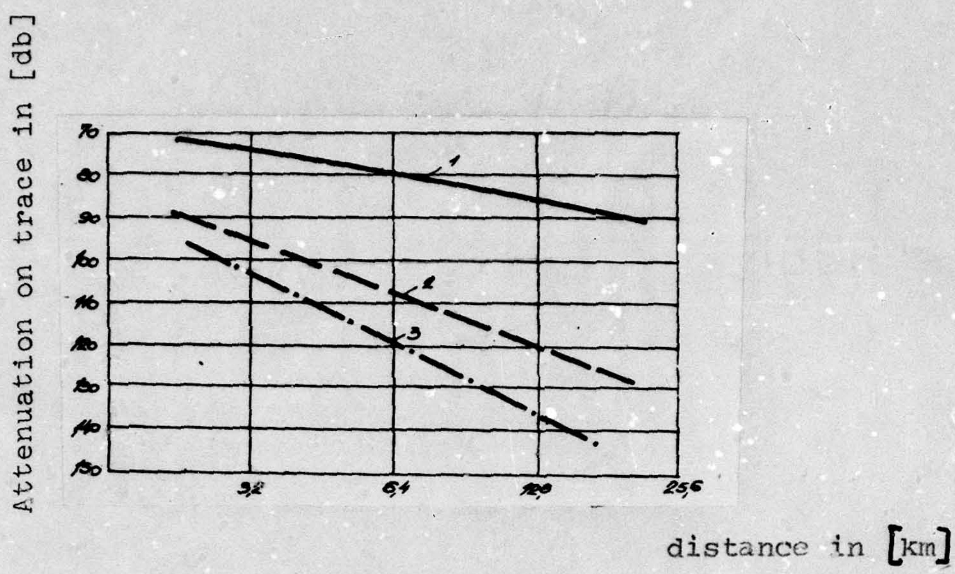


Figure 6.1.

Attenuation during radio wave propagation: 1 - in free space, 2 - above ideally even earth's surface, 3 - above real earth's surface

octave corresponds to propagation above average relief of earth's surface, which is the case which best corresponds to jamming of ground means of communications by ground jammers. Simply speaking, this means that in the case when the distance between the jammer and the jammed receiver is twice as large as the distance between the receiver and the transmitter, then the power of the jammer must be at least 15 db (32 times) larger than the power of the transmitter.

6.1.1. JAMMING OF COMMUNICATIONS ABOVE EARTH'S SURFACE

The situation which appears during jamming of ground communications is shown in Fig. 6.2.

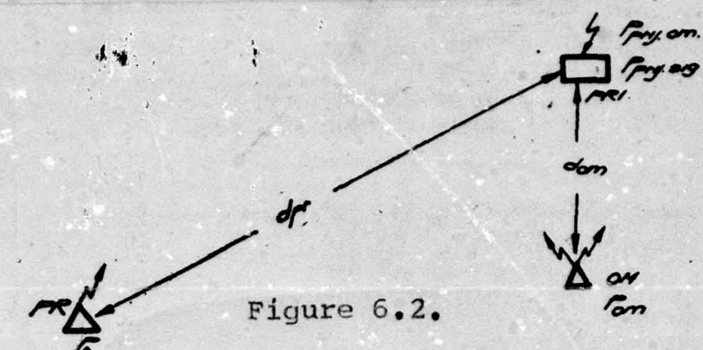


Figure 6.2.

Jamming of ground radio communications:

(PRED = power transmitter P_{pr}; PRIJ = receiver; OM = jamming transmitter of power P_{om}; d_{pr} = signal trace;

d_m = jamming trace)

Using Curve 3 in Fig. 6.1, one can write equation 6.1. in the form

$$\gamma = \frac{P_{prij.\ om}}{P_{prij.\ sig}} = \frac{P_{om}}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^5 \qquad (6.2)$$

(designations the same as in Fig. 6.2.).

If factor γ, power of the transmitter whose receiver we wish to jam, and the distance are known, then one can from (6.2) calculate the transmitter power necessary for the jamming

$$P_{om} \geqslant \gamma \cdot P_{pr} \left(\frac{d_{om}}{d_{pr}}\right)^5 \qquad (6.3)$$

Usually the quantities P_{pr}, P_{om} represent the distance. Then we put the following power and ranges in the ratio

$$\frac{P_{om}}{P_{pr}} = \gamma \left(\frac{d_{om}}{d_{pr}}\right)^5 \qquad (6.4)$$

then one can plot the diagram in Fig. 6.3, from which it is simple to find the necessary power ratios.

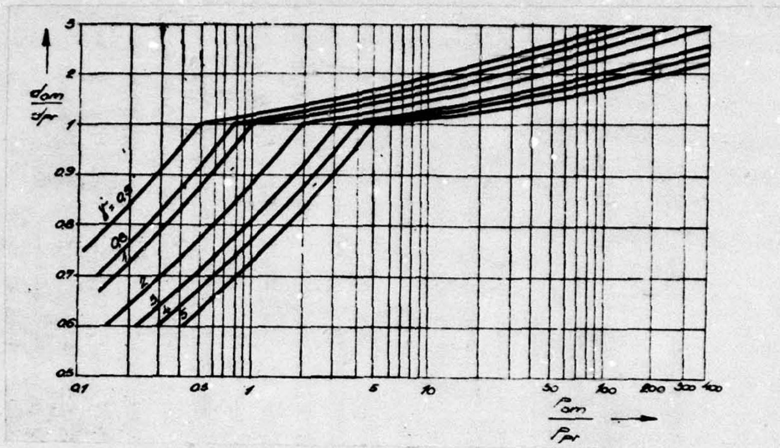


Figure 6.3.

Dependence of the jammer power on the distance
and the jamming factor.

The usual values for jamming factor γ are:

- for jamming of amplitude-modulated signals by noise $\gamma = 0.5 - 1$;
- for jamming of frequency-modulated signals $\gamma = 1 - 1.5$;
- for jamming of pulse-modulated signals $\gamma = 1 - 2$.

When the transmitter and the receiver of the means of communications and the jamming installation use non-directed antennas, a spherical field forms around the jamming transmitter antenna, in which the reception of the useful (intelligent) signal is impossible.

The boundary distance at which jamming is possible is

$$d_{om} = d_{pr} \sqrt[3]{\frac{1}{\gamma} \cdot \frac{P_{om}}{P_{pr}}} \qquad (6.5)$$

From the diagram in Fig. 6.3 it is seen that it is energywise the most favorable if the distance ratio d_{om}/d_{pr} is equal to unity or less, which means that the jamming transmitter must be at the same

or lesser distance from the jammed receiver than is the distance of the transmitter of the means of communications. On the contrary, the power of the jamming transmitter must be considerably higher for effective jamming.

In practice there frequenctly appears a need to put out of action the receiver at a certain sector, or that jamming in the other directions is not desirable. In this case a jamming transmitter with a directed antenna is used (Fig. 6.4).

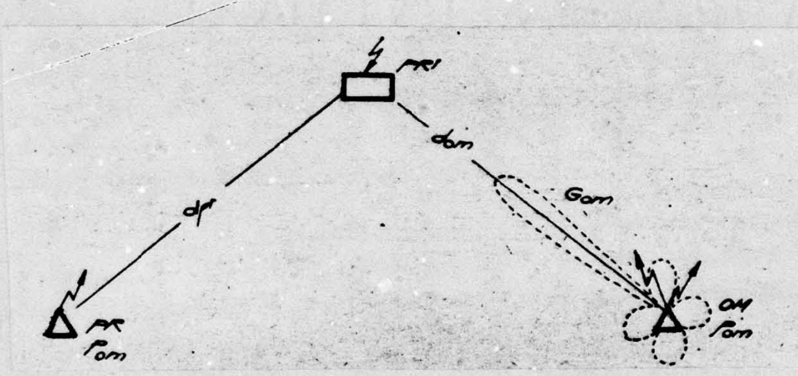


Figure 6.4.

Jamming of ground means of communications by a jammer with directed action.

The required transmitter power for jamming which uses a directed antenna with amplification G_{om} is equal to

$$P'_{om} \geqslant \gamma \cdot \frac{P_{pr}}{G_{om}} \left(\frac{d_{om}}{d_{pr}}\right)^{2} \qquad (6.3a)$$

Here, G_{om} is the amplification factor of jammer antenna with respect to the isotropic source and it is equal to

$$G_{om} = \frac{27000}{2 \cdot \Delta\beta \cdot 2\Delta\varepsilon} \quad \text{or} \quad G_{om} = \frac{4\pi A}{\lambda^{2}}$$

where: $\Delta\beta$ and $\Delta\varepsilon$ = beam width in azimuthal and eleveational plane,

A = effective surface of the antenna,

λ = antenna wavelength.

The boundary (limiting) distance at which jamming is still possible amounts to

$$d'_{om} = d_{pr} \sqrt[3]{\frac{1}{\gamma} \cdot \frac{P_{om} \cdot G_{om}}{P_{pr}}} \quad (6.5a).$$

From the point of view of the means of communications, their jamming can in many ways be made difficult to the extent that the participant receivers and transmitters use directed (directional) antennas (Fig. 6.5). If the same transmitter and receiver are used

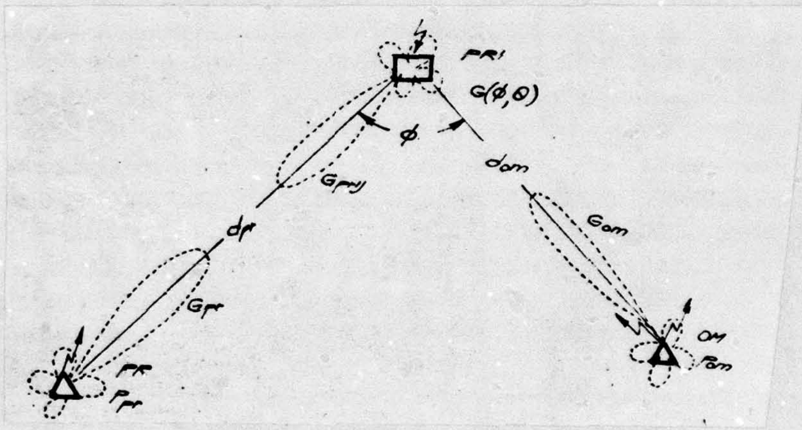


Figure 6.5.

Application of directed antennas for ground communications and their jamming.

as in the case of nondirected communications, then the strength of the useful signal at the reception site increases in propoertion to $G_{pr} \cdot G_{prij}$.

Tha jamming signals are taken as one of the lateral fans of the receiver. As which lateral fan the jamming signal will be taken depends on the spatial position of the receiver—transmitter direction with respect to the receiver—jammer direction. The number of lateral fans, their spatial distribution, and their amplification factor

depend on the construction design and position of the antennas.

If the receiver and the transmitter use a directed antenna, and the jammer uses a non-directed antenna, then the equation fro the jamming factor (6.2) acquires the form

$$\gamma' \leqslant \frac{P_{prtj \cdot om}}{P_{prtj \cdot sig}} = \frac{P_{om} \cdot G(\Phi,\theta)}{P_{pr} \cdot G_{pr} \cdot G_{prtj}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^{5} \tag{6.2b}$$

If all three antennas are equipped with directed action, then

$$\gamma''' \leqslant \frac{P_{prtj \cdot om}}{P_{prtj \cdot sig}} = \frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta)}{P_{pr} \cdot G_{pr} \cdot G_{prtj}} = \left(\frac{d_{pr}}{d_{om}}\right)^{5} \tag{6.2c}$$

The necessary power when the receiver and the transmitter antennas are directed and the jammer antenna is non-directed is

$$P''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prtj}}{G(\Phi,\theta)} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^{5} \tag{6.3b}$$

and when all three antennas are directed, it is

$$P'''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prtj}}{G_{om} \cdot G(\Phi,\theta)} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^{5} \tag{6.3c}$$

Analogously to the preceding cases, the equation for the boundary jamming range (6.5) acquires in the first case (receiver and transmitter antennas sirected, and the jammer antenna non-directed) the form

$$d''_{om} = d_{pr} \sqrt[5]{\frac{P_{om} \cdot G(\Phi,\theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prtj}}} \tag{6.5b}$$

and when all three antennas aredirected, then

$$d'''_{om} = d_{pr} \sqrt[5]{\frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prtj}}}, \tag{6.5c}$$

The estimations as of up to the presentday are based on the assumption that the permeable range and the frequency at which the receiver is attuned coincides with the emitted frequency width of the jamming transmitter. Likewise it was assumed that polarizations

of the antenna beams of the signal transmitter and the jamming transmitter are equal.

To the extent that this is not the case, the equations (6.2a, b,c, 6.3a, b,c, and 6.5a,b,c) must be corrected by nonharmonization factors. The nonharmonization factor of frequency ranges is:

$$\eta_1 = \frac{\Delta f_{prij}}{\Delta f_{om}} \tag{6.6}$$

where Δf_{prij} = permeable range of the jammed receiver around attunement frequency.

Δf_{om} = emitted frequency width of jamming transmitter. The nonharmonization polarization factor is

$$\eta_2 = 0{,}5 - 1 \tag{6.7}$$

η_2 = 0.5 if the jamming transmitter has circular polarization. The corrected forms of the equations (designations with index K) are:

jamming factor:

eq. (6.2) $$\gamma_k = \frac{P_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}} \left(\frac{d_{pr}}{d_{om}}\right)^5 \tag{6.2d}$$

eq. (6.2b) $$\gamma''_k = \frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^5 \tag{6.2f}$$

eq. (6.2c) $$\gamma'''_k = \frac{P_{om} \cdot G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^5 \tag{6.2g}$$

The required jamming transmitter power with frequency width Δf_{om} is:

eq. (6.3) $$P_{om,k} = \gamma \cdot \frac{P_{pr}}{\eta_1 \eta_2} \left(\frac{d_{om}}{d_{pr}}\right)^5 \tag{6.3d}$$

eq. (6.3a) $$P'_{om,k} = \gamma \cdot \frac{P_{pr}}{G_{om} \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^5 \tag{6.3e}$$

eq. (6.3b) $$P''_{om,k} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^5 \tag{6.3f}$$

eq. (6.3c) $$P'''_{om,k} = \gamma \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^5 \tag{6.3g}$$

The boundary distance to which jamming is possible is:

eq. (6.5) $$d_{om,k} = d_{pr} \cdot \sqrt[5]{\frac{1}{\gamma} \cdot \frac{P_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}}} \qquad (6.5d)$$

eq. (6.5a) $$d'_{om,k} = d_{pr} \sqrt[5]{\frac{1}{\gamma} \cdot \frac{P_{om} \cdot G_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}}} \qquad (6.5e)$$

eq. (6,5b) $$d''_{om,k} = d_{pr} \sqrt[5]{\frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{pr(j)}}} \qquad (6.5f)$$

eq. (6.5c) $$d'''_{om,k} = d_{pr} \sqrt[5]{\frac{P_{om} \cdot G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{pr(j)}}} \qquad (6.5g)$$

6.1.2. JAMMING OF COMMUNICATIONS ABOVE SEA SURFACE

Geometrical arrangement of the transmitter and the receiver of jammed communications, as well as of the jamming transmitter and the antenna combination, can basically be as shown in Figs. 6.2, 6.4, and 6.5.

Since it has been empirically shown that attenuation above sea surface increases by 12 db per octave (Curve 2 in Fig. 6.1), the samples for the estimation of the jamming parameters of communications above earth's surface (Points 6.1.1) acquire the following forms (same designations being used).

<u>Non-directed transmitter, receiver, and jammer antennas:</u>

The jamming factor is

$$\gamma = \frac{P_{om}}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \qquad (6.6)$$

$$\gamma_k = \frac{P_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \qquad (6.6d)$$

The required power of the jamming transmitter of frequency width Δf_{om} is:

$$P_{om} = \gamma \cdot P_{pr} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^4 \qquad (6.7)$$

$$P_{om,k} = \gamma \cdot \frac{P_{pr}}{\eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^4 \qquad (6.7d)$$

The boundary distance to which jamming is possible is:

$$d_{om} = d_{pr} \sqrt[4]{\frac{1}{\gamma} \cdot \frac{P_{om}}{P_{pr}}} \qquad (6.8)$$

$$d_{om,k} = d_{pr} \sqrt[4]{\frac{1}{\gamma} \cdot \frac{P_{om} \cdot \eta \cdot \eta_1 \cdot \eta_2}{P_{pr}}} \qquad (6.8d)$$

<u>Transmitter and receiver antennas non-directed, and jammer antenna directed</u>

The jamming factor is:

$$\gamma' = \frac{P_{om} \cdot G_{om}}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \qquad (6.6a)$$

$$\gamma'_k = \frac{P_{om} \cdot G_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \qquad (6.6e)$$

The required power for the jamming transmitter of frequency width Δf_{om} is:

$$P'_{om} = \gamma \cdot \frac{P_{pr}}{G_{om}} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^4 \qquad (6.7a)$$

$$P'_{om\,k} = \gamma \ \frac{P_{pr}}{G_{om} \cdot \eta_1 \cdot \eta_2} \ \left(\frac{d_{om}}{d_{pr}}\right)^4 \qquad (6.7e)$$

The boundary distance to which jamming is possible is:

$$d'_{om} = d_{pr} \sqrt[4]{\frac{P_{om} \cdot G_{om}}{\gamma \cdot P_{pr}}} \qquad (6.8a)$$

$$d'_{om,k} = d_{pr} \cdot \sqrt[4]{\frac{P_{om} \cdot G_{om} \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr}}} \qquad (6.8e)$$

<u>Transmitter and receiver antennas directed, and jammer antenna non-directed</u>:

The jamming factor is:

$$\gamma'' = \frac{P_{om} \cdot G(\Phi, \theta)}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \qquad (6.6b)$$

$$\gamma''_k = \frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \tag{6.6f}$$

The require power for jamming transmitter with frequency width Δf_{om} is:

$$P''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G(\Phi, \theta)} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \tag{6.7b}$$

$$P''_{om,k} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \tag{6.7f}$$

The boundary distance to which jamming is possible is:

$$d''_{om} = d_{pr} \sqrt[4]{\frac{P_{om} \cdot G(\Phi, \theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \tag{6.8b}$$

$$d''_{om,k} = d_{pr} \sqrt[4]{\frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \tag{6.8f}$$

<u>Directed transmitter, receiver, and jammer antennas</u>:

The jamming factor is

$$\gamma''' = \frac{P_{om} \cdot G_{om} \cdot G(\Phi, \theta)}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^4 \tag{6.6c}$$

$$\gamma'''_k = \frac{P_{om} \cdot G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \tag{6.6g}$$

The required power for jamming transmitter with frequency width Δf_{om} is:

$$P'''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G_{om} \cdot G(\Phi, \theta)} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^4 \tag{6.7c}$$

$$P'''_{om,k} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^4 \tag{6.7g}$$

The boundary distance to which jamming is possible is:

$$d'''_{om} = d_{pr} \sqrt[4]{\frac{P_{om} \cdot G_{om} \cdot G(\Phi \cdot \theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \tag{6.8c}$$

$$d'''_{om,k} = d_{pr} \sqrt[4]{\frac{P_{om} \cdot G_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \tag{6.8g}$$

6.1.3. JAMMING OF COMMUNICATIONS IN FREE SPACE

In case of air—air, ground—air, and very directed communications at the centimetric wave region (radio relay communications) the trace of propagation of electromagnetic waves moves through the air or remains sufficiently removed from all objects on earth's surface. For this reason one can in the enumerated cases say that the propagation and the attenuation is identical to the propagation and attenuation in free space.

For the propagation in free space the samples for the estimation of the jamming parameters from Point 6.1 acquire these forms (used are the same designations and jamming combinations as in Point 6.1.1.):

<u>Non-directed transmitter, receiver, and jammer antennas</u>:

The jamming factor is:

$$\gamma = \frac{P_{om}}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \tag{6.9}$$

$$\gamma_k = \frac{P_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \tag{6.9d}$$

The required power of jamming transmitter of frequency width Δf_{om} is:

$$P_{om} = \gamma \cdot P_{pr} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \tag{6.10}$$

$$P_{om,k} = \gamma \cdot \frac{P_{pr}}{\eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \tag{6.10d}$$

The boundary distance to which jamming is possible is:

$$d_{om} = d_{pr} \sqrt{\frac{1}{\gamma} \cdot \frac{P_{om}}{P_{pr}}} \tag{6.11}$$

$$d_{om,k} = d_{pr} \sqrt{\frac{P_{om} \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr}}} \tag{6.11d}$$

<u>Transmitter and receiver antennas non-directed, and the jammer antenna directed</u>:

$$\gamma' = \frac{P_{om} \cdot G_{om}}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \tag{6.9a}$$

$$\gamma'_k = \frac{P_{om} \cdot G_{om} \cdot \eta_1 \cdot \eta_2}{P_{pr}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \qquad (6.9e)$$

The required power for jamming transmitter of frequency width Δf_{om} is:

$$P'_{om} = \gamma \cdot \frac{P_{pr}}{G_{om}} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \qquad (6.10a)$$

$$P'_{om,k} = \gamma \cdot \frac{P_{pr}}{G_{om} \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \qquad (6.10e)$$

The boundary distance to which jamming is possible

$$d'_{om} = d_{pr} \sqrt{\frac{P_{om} \cdot G_{om}}{\gamma \cdot P_{pr}}} \qquad (6.11a)$$

$$d'_{om,k} = d_{pr} \sqrt{\frac{P_{om} \cdot G_{om} \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr}}} \qquad (6.11e)$$

<u>Transmitter and receiver antennas directed, and the jammer antenna non-directed</u>:

The jamming factor is:

$$\gamma'' = \frac{P_{om} \cdot G(\Phi, \theta)}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \qquad (6.9b)$$

$$\gamma''_k = \frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \qquad (6.9f)$$

The required power for jamming transmitter with frequency width Δf_{om} is:

$$P''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G(\Phi, \theta)} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \qquad (6.10b)$$

$$P''_{om,k} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \qquad (6.10f)$$

The boundary distance to which jamming is possible is:

$$d''_{om} = d_{pr} \sqrt{\frac{P_{om} \cdot G(\Phi, \theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \qquad (6.11b)$$

$$d''_{om,k} = d_{pr} \sqrt{\frac{P_{om} \cdot G(\Phi, \theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \qquad (6.11f)$$

<u>Directed antennas of transmitter, receiver, and jammer</u>:

The jamming factor is:

$$\gamma''' = \frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta)}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \quad (6.9c)$$

$$\gamma'''_k = \frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta) \cdot \eta_1 \cdot \eta_2}{P_{pr} \cdot G_{pr} \cdot G_{prij}} \cdot \left(\frac{d_{pr}}{d_{om}}\right)^2 \quad (6.9g)$$

The required power of jamming transmitter with frequency width Δf_{om} is:

$$P'''_{om} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G_{om} \cdot G(\Phi,\theta)} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \quad (6.10c)$$

$$P'''_{om,k} = \gamma \cdot \frac{P_{pr} \cdot G_{pr} \cdot G_{prij}}{G_{om} \cdot G(\Phi,\theta) \cdot \eta_1 \cdot \eta_2} \cdot \left(\frac{d_{om}}{d_{pr}}\right)^2 \quad (6.10g)$$

The boundary distance to which jamming is effective is:

$$d'''_{om} = d_{pr} \cdot \sqrt{\frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta)}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \quad (6.11c)$$

$$d'''_{om,k} = d_{pr} \cdot \sqrt{\frac{P_{om} \cdot G_{om} \cdot G(\Phi,\theta) \cdot \eta_1 \cdot \eta_2}{\gamma \cdot P_{pr} \cdot G_{pr} \cdot G_{prij}}} \quad (6.11g)$$

6.1.4. JAMMING OF DIRECTED RADIO COMMUNICATIONS (RRV)

Directed or radio relay communications are considered to be those communications which are the hardest to jam. Characteristic for them is that due to higher range and unjammed propagation, the terminal, starting, and intermediate stations are placed on more elevated and dominating points on the route, which in many ways facilitates the detection of their location. The antenna diagram is as a rule very so narrow (to the extent that its wavelength is smaller and the antenna larger, its width is also smaller) and in the majority of the cases on the route itself in the horizontal position or under minimal positive or negative elevation slope (Fig. 6.6). Such an arrangement of antenna beams almost always enables the "throwing in" of the main beam of the jamming installation into the main beam of the directed communications. Because of this, the directed

communications are jammed indirectly, using some of the following methods:

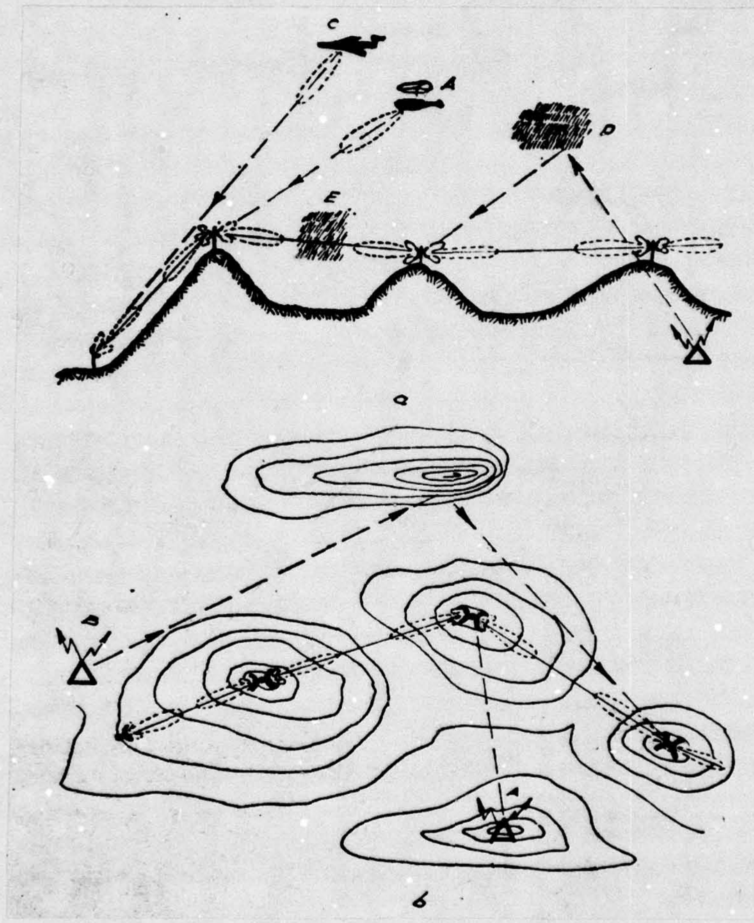


Figure 6.6.

Some of the countermeasure methods on the route of directed communications; a - vertical cut of the route, b - view from above.

- use of lateral fans of the directed communications for the insertion (throwing in) of the main beam of the jamming installation which is located on suitable elevations or on aircraft (case A in Fig. 6.6);

- use of reflection of the jamming beam from suitable natural (artificial) objects in the area surrounding the route (case B in Fig 6.6);

- air jamming of terminal stations, in case of which the beam is at higher slope (case C in Fig. 6.6);

- creation of artificial passive dipole clouds in the vicinity of the route and their use as passive reflector for the jamming beam (e.g. D in Fig. 6.6);

- creation of artificial passive dipole clouds on the route itself, whereby - due to increased attenuation - its interruption is provoked (example E in Fig. 6.6). The estimation is the same as in case of Point 9.1.2 (p. 230 on original copy; p. 265 of translation).

The estimations of the necessary powers for the jamming installations, as a function of the distance, are given in Point 6.1. Here one must always take care that the amplifications and the radiated powers are always used in the directions of the lateral fans which are being used for the jamming.

6.2. KINDS OF JAMMING SIGNALS

The most effective jamming is obtained if the jamming signal has the same characteristics as the signal by which communications are broadcast. Thus, against a signal with amplitudinal modulation it is the most suitable to also use an amplitude-modulated jamming signal, whereas against frequency-modulated signals, it is the most convenient to use a frequency-modulated jamming signal, and so on.

With respect to the method of transfer of the information, the means of communication are divided into:

- linear ones, in which the information linearly affects the variations in amplitude, frequency, phase, or duration of the signal of the carrier, and

- dicrete one, in which the information is transmitted in the digital form. In this case, the shape of the carrier signal has nothing in common with the information transmitted.

According to the above division, linear are all the systems with amplitudinal, frequency, phase, and pulse modulation. The various pulse-code systems, delta and similar methods of modulation belong to the discrete method of transmission of information.

The quality of the transmission of the information characterizes its understandability [intelligibility] coefficient. Under understandability is understood the number of correctly transmitted letters, words, or symbols per the total number transmitted within the same unit of time. Therefore, the objective of the jamming of means of communications is the decrease of this coefficient of understandability in a most convenient and a most economical way.

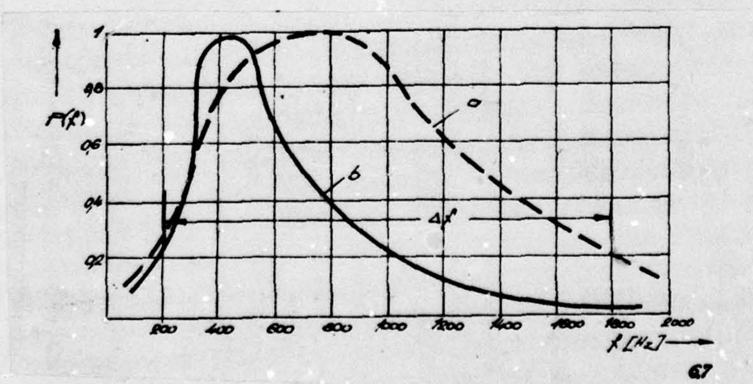


Figure 6.7.
Energy spectrum of the spoken language; a - Croatian language*, b - Russian language; Δf = part of the energy spectrum which is essential for understandability.

---

*Dr. Vladimir Matković, graduate engineer: Ph.D. dissertation, Entropy of the Croatian Language, University of Zagreb, 1961.

If by means of articulation tables one takes down the pattern of the spoken language, a diagram such as in Fig. 6.7 is obtained, from which it is seen that energy level of each frequency within the range of the spoken frequencies.

By international recommendations it is confirmed that it suffices for the corresponding quality of transmission of the signal to transmit the frequency range from 300 to 3600 Hz (300 - 2500 Hz). All means of communications are also constructed (designed) for these widths.

If we consider that for understandable transmission of information are important all the frequencies which participate in the energy spectrum by more than 20%, then we obtain for the transmission essential frequency band Δf from 200 to 1800 Hz.

If the jamming transmitter emits signals which will - together with the intelligent signal - at the reception site make impossible the differentiation of the characteristics of the frequency spectrum essential for understandability, then the transmitted information will be nonunderstandable and the mission of the jamming will have been fulfilled.

Since in case of various types of modulation the information is contained in some other form, we shall get familiar with them from the point of view of jamming.

6.2.1. NONMODULATED TELEGRAPHY (A_1)

The information is transmitted by interruption of the carrying wave. The low-frequency component of the information is established in the receiver(by additional mixing, beating, or in a similar way).

In the receiver there are generally very sharp filters which enable good selection of the desired frequency.

Jamming can be done by nonmodulated or pulse-modulated signal with precisely attuned transmission and jamming frequencies. An even more effective way, but energy-wise less convenient, is the wide-band jamming modulated by noise of pulse exchange of several frequencies within a low-frequency component which emerges on the receiver. The optimal width of such a frequency range is the width of the permeable range of the receiver.

The parameters for the jamming: power of jamming transmitter P_{om}, distance of jamming d_{om} and jamming factor γ, everything according to equations and combinations from Point 6.1 (p. 124 of copy; p. 143 of translation).

The frequency of the jamming transmitter is equal to the frequency at which the communications unfolds. The frequency width of the jamming signal is equal to the width of the permeable range of the receiver.

6.2.2. AMPLITUDINAL MODULATION (A_2, A_3)

The instantaneous value of an amplitude-modulated signal for the modulation with a single frequency is

$$i = I_0(1 + m\cos\Omega t)\cos(\omega_0 t + \varphi) \qquad (6.12)$$

where: $\Omega = 2\pi f_m$ $\qquad$ f_m = modulation frequency

$\omega_0 = 2\pi f_o$, $\qquad$ f_o = frequency of the carrying wave

m = degree of modulation, φ = phase shift.

The antenna radiates the combination

$$i = I_0 \cos \omega t + I_0 \frac{m}{2} \cos(\omega + \Omega) t + I_0 \frac{m}{2} \cos(\omega + \Omega) t \qquad (6.13)$$

where

$I_0 \cos \omega t$ is carrying wave (6.14)

$$\left.\begin{matrix} I_0 \frac{m}{2} \cos(\omega + \Omega) \\ I_0 \frac{m}{2} \cos(\omega - \Omega) \end{matrix}\right\} \text{ are lateral belts} \qquad (6.15)$$

If for f_m are taken the boundary values of the modulation frequency (f_d, f_g), then the energy spectrum of equation (6.13) can be - depending on the frequency - represented as in Fig. 6.8.

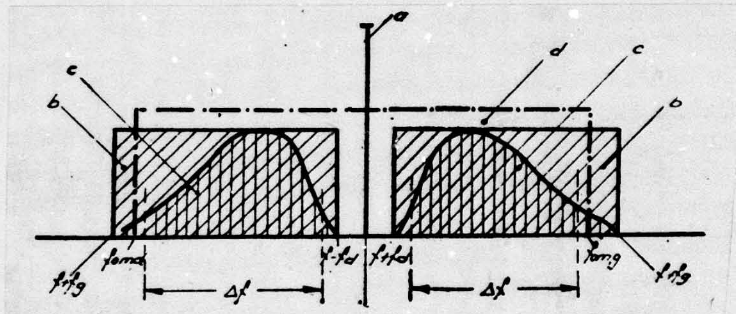


Figure 6.8.

Frequency spectrum of amplitude-modulated signal: a - carrying wave, b - theoretical lateral belt, c - normal lateral belt for transmission of spoken spectrum, Δf - essential frequencies for transmission of speech, d - energy level of jamming signal.

The power radiated by the antenna is

$$P = \frac{I_0^2 R}{2}\left(1 + \frac{m^2}{2}\right) \qquad (6.16)$$

or expressed with respect to the power of the carrying wave P_0 it is

$$P = P_0\left(1 + \frac{m^2}{2}\right) \qquad (6.17)$$

Equations (6.17; 6.13, or 6.14, respectively; 6.15) are important for active jamming.

From equation (6.13) it is seen that the information is transmitted by the top and the bottom lateral belt whose width depends on the frequency width of the modulation frequency ($f_g - f_d$).

The total width of the transmitted signal (both lateral belts) is 2 f_m.

From equation (6.17) it is seen that the power which the transmitter radiates in lateral ranges is equal to

$$P_{bot} = P_o \cdot \frac{m^2}{2} \qquad (6.18)$$

Inside the lateral belts (bands) are the frequencies which are essential for transmission of information (Δf in Fig. 6.8).

The amplitude-modulated signal can be jammed in the following ways:

a) by emission of the carrying wave $f_{om} = f_{pred}$, with lateral belts with width Δf = 200 - 1,800 Hz. Modulation can be done by white noise or complex tones of the same amplitude within the 200 to 1,800 Hz region. The emitted power inside the lateral belts of the jammer must be at least the same if not larger than the power in the lateral belts of the transmitter

$$P_{bot,om} \geqslant P_{bot,pred} = P_o \cdot \frac{m^2}{2} \qquad (6.19)$$

which can be attained by a higher degree of modulation m or a higher power of the carrying wave P_o.

For the power of the transmitter of the communications and the transmitter of jamming there are taken now from Point 6.1 (p. 124 of original copy; p. 143 of translation) in this case the powers of the lateral belts of the transmitter of the communications and the

transmitter of jamming

$$P_{om} = P_{om,boč} - P_{o,om} \cdot \frac{m^2}{2} \tag{6.20}$$

$$P_{pr} = P_{pr,boč} - P_{o,pr} \cdot \frac{m^2}{2} \tag{6.21}$$

using equations (6.20 and 6.21) the parameters for all the combinations given in Point 6.1 (p. 124 of original copy; p. 143 of translation) can be calculated.

b) by emitting of nonmodulated carrying wave of power P_{om}, which would wobble along the frequency range from $f-f_g$ to $f+f_g$ at some frequency from the essential range Δf(200 - 1,800 Hz). The powers are identical as in the preceding case;

c) by amplitude—frequency modulated signal, namely:

- amplitudinal modulation by constant tone from the essential frequency region Δf(200 - 1800 Hz)

- frequency modulation with deviation $\pm \Delta f$

The power ratios are the same as in the case under a.

For amplitudinal modulation and various ways of jamming the experimentally determined jamming factor is given in Fig. 6.9.

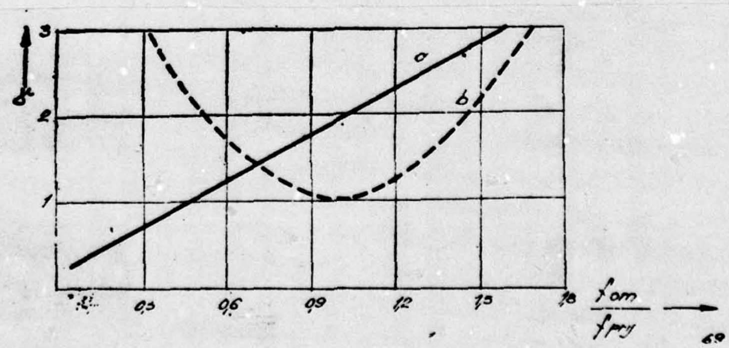


Figure 6.9.

Jamming factor γ as a function of nonharmonization between the jammer and the jammed receiver for various kinds of jamming: a - amplitude—frequency modulated jamming signal, b - frequency-modulated jamming signal by noise.

6.2.3. UNILATERAL TRANSMISSION (A3 - a,h,i)

Transmission of a single lateral belt is done three ways

- with carrying frequency (a in Fig. 6.10);
- with attenuated carrying frequency - pilot-signal (b in Fig. 6.10);
- without carrying frequency (c in Fig. 6.10).

In the transmitter is created a complete signal, the unnecessary components are cut off by the very sharp filters, and the thus received signal is amplified and led to the transmitter antenna.

The jamming can be done by:

a) identical unilateral signal modulated by white noise or a frequency combination from the essential region Δf.

b) all methods from Point 6.2.2 (p. 142 of original copy; p. 161 of translation);

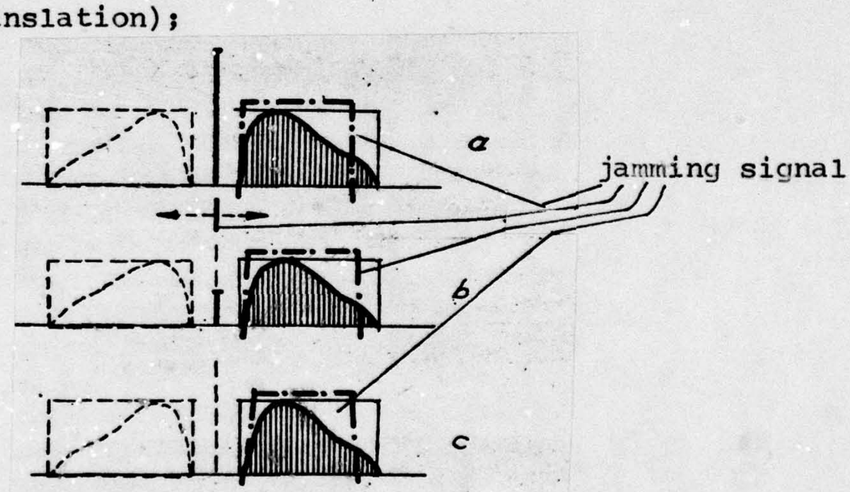


Figure 6.10.

Kinds of unilateral transmissions.

c) in case b, with attenuated carrier, by emitting of an amplitudinally greater carrier and its rapid change along the low frequency region. Then the receiver reference oscillator shall walk along with the changeable pilot-signal, and the result shall be - a nonintelligible reproduction of information

6.2.4. FREQUENCY AND PHASE MODULATION

In case of frequency modulation the frequency of the carrying wave varies in the rhythm of the modulation frequency. The instantaneous value of the signal is

$$i = I_0 \cos\left(\omega_0 t + m_f \cdot \frac{\omega_0}{t} \sin \Omega t\right) \tag{6.22}$$

where: frequency change = $\omega(t) = \omega_0(1 + mt \cos \Omega t)$;

mf = frequency modulation factor;

$\omega_0 = 2\pi f_o$ = central frequency;

$\Omega = 2\pi f_m$ = modulation frequency.

The frequency deviation amounts to

$$M_f = m_f \frac{\omega_0}{\Omega} = \frac{\Delta \omega}{\Omega} \tag{6.23}$$

Depending on frequency deviation and frequency of the modulated signal, a greater or smaller number of lateral belts appears, forming a wider or narrower spectrum. Its width for the needs of the jamming can be rather accurately determined by means of the expression

$$\Delta f \approx 2\pi f_m \cdot (1 + M_f + \sqrt{M_f}) \tag{6.23a}$$

In case of phase modulation, the phase of the signal varies in the rhythm of the modulation frequency. The instantaneous value of the signal is

$$i = I_0 \cos(\omega_0 t + \varphi_0 + \Phi_m \sin \Omega t) \tag{6.24}$$

where the phase change is

$$\varphi(t)=\varphi_0+\Phi_m \sin \Omega t \leqslant 90^{\circ}$$

and the phase deviation $\Phi_m = m \cdot \varphi_0$; here the frequency varies with $\Delta f = f_m \cdot \Phi_m$.

If equations (6.22) and (6.24) are used, it is seen that both modulations have the same value, with the exception that in case of frequency modulation the change in the frequency is a reflection (echo) of the modulation frequency, with the change in phase being a consequence of it, while in case of phase modulation the reverse is true.

Jamming of frequency and phase modulation is therefore done by frequency or phase modulated signal with at least one frequency or phase deviation. For output powers of the jamming transmitter and the jamming ranges in various combinations the equations given in Point 6.1 (p. 124 of original copy; p. 143 of translation) correspond.

6.2.5. PULSE MODULATION

The carrier of information in pulse modulation can be:

- pulse height (h);
- pulse duration (τ);
- pulse repetition frequency (f_{pon});
- pulse position with respect to the position without the modulation signal (similar to phase modulation).

The cited modulation forms are presented in Fig. 6.11.

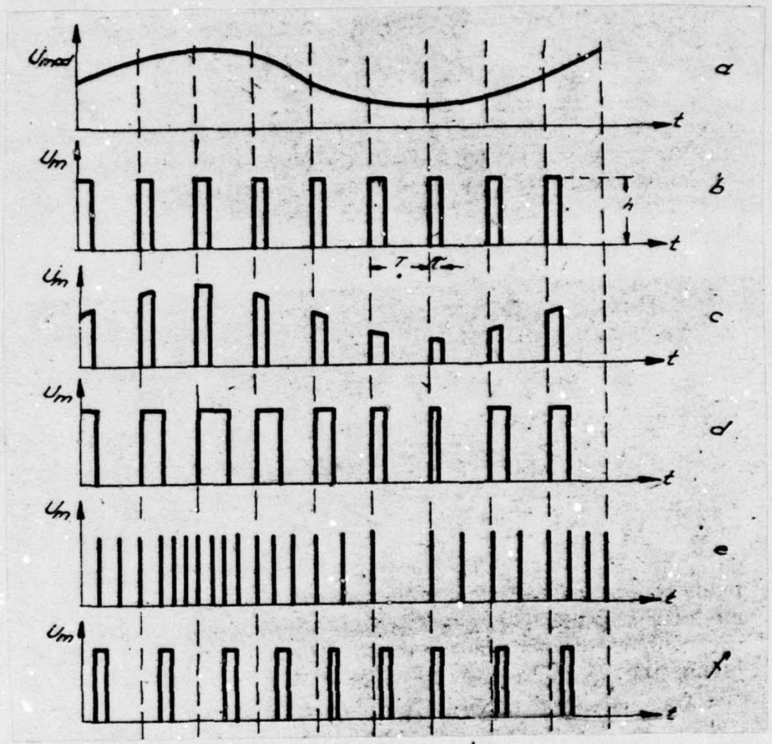


Figure 6.11.

Kinds of pulse modulation: a - modulation frequency, b - carrying pulse signal without modulation, c - amplitudinal modulation, d - width modulation, e - frequency pulse modulation, g - phase modulation

In case of multi-channel pulse modulation several pulses information carriers are squeezed into the spacing between two synchronization pulses. This principle is shown in Fig. 6.12.

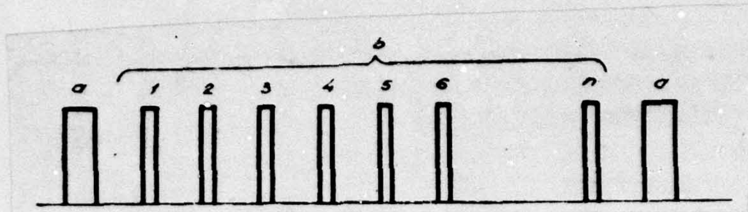


Figure 6.12.

Principle of multi-channel pulse modulation: a - synchronization pulses, b - pulses information carriers, channels 1 . . n.

The modulation of each individual channel is done by one of the previously described methods.

The most convenient method of jamming of all kinds of pulse modulations is the emitting of nonsynchronized pulses of the same or greater power with the repetition frequency

$$f_{pon,om} = n \cdot f_{pon,imp} = n \cdot \frac{1}{T} \tag{6.25}$$

where n = 2,3......

In this case n jamming pulses are squeezed into the space between two neighboring pulses. The amplitude of the jamming pulse must be at least equal to the amplitude of the signal without modulation. In case of multi-channel pulse modulation it suffices to throw in a new nonsynchronized or timewise intentionally variable synchronized pulse and thereby disturb successive separation of individual channels and thus "line by line" mutually mix up the information in the channels.

The estimations of the powers and the ranges are done entirely by the method given in Point 6.1 (p. 124 of original copy; p. 143 of translation) with the following comments:

- transmitting powers of the transmitter and the jammer are of the pulse-type;

- duration of the jammer pulse must be at least as long as the duration of the pulse of the transmitter of the communications;

- harmonization of the carrying frequencies must be present;

- jamming factor γ is greater than 1.

In addition, the pulse-modulated transmitting signal can be interfered with by any of the methods used for interference of pulse-radar installations, such as described in Item 8.1

6.3 STRAY INTERFERENCE

Every radio receiver device has a certain bandwidth of the permeability range within which signals are received, regardless of the modulation mode. All signals received by the receiver within this permeability range are reproduced at the output stage of the receiver. The permeability range of the receiver for amplitude modulation is at least double the upper frequency modulation of the receiver, being single upper modulation frequency for unilateral transmission, while for the receiver with frequency modulation it is the spectral width of the lateral bands (equation 6.23a), and the like.

All signals from any source received by the receiver antenna which by their frequency are within its permeability range represent to the receiver an interfering signal (unless they are intelligent signals) with identical results as from an interference signal.

In amplitude modulation, the simultaneously received intelligent and/or interfering amplitude-modulated signals in the receiver are added up by vectoring. The resultant signal has the characteristics of amplitudinal and frequency modulation with beat-frequency tone.

In frequency modulation, the simultaneously received frequency-modulated intelligent signal and amplitude-modulated interfering signal do not represent such an interference, since the receiver is insensitive to

amplitude modulation. A large spectral width of lateral bands and their various amplitudes decrease the effect of the lateral bands of the interfering amplitude-modulated signal. If both signals are frequency-modulated, beat frequency appears at every single lateral band.

Communication means which are close in frequency and in location affect one another. Their effect can be determined entirely on the basis of the procedures given in Item 6.1
by commenting that one must always consider those forces which are actually taking part in producing the interference.

VII RADAR COUNTERMEASURES

Since radar installations provide initial data to a large number of various army systems, one can - by undertaking radar countermeasures - paralyze not only individual installations, but also complex systems.

The purpose of a radar installation is to provide accurate coordinates of air-, ground-, or open sea targets at the greatest possible distances, or to produce as accurate as possible data on the earth surface, or objects on it, for combat or navigation purposes. However, the radar lookout must be confident that the data displayed on the screen of the radar indicator represent the true situation.

In view of the fact that the majority of military radar installations in operation frequently operate in enemy air space (extending radiation diagrams across territorial borders), in contrast to communication means which predominantly operate in its own space, they are also more exposed to enemy countermeasures.

The development of radar countermeasures parallels the development and progress of radar technology. At one time, the development of radar technology was strongly characteristic of radar defense, whereas in the development of today the trend is in the production and application of installations immune to countermeasures. All in all, it is still technologically impossible to produce radar installations immune to all countermeasures. Therefore, it is the ultimate goal in the development of radar installations and measures of defense against electronic countermeasures to develop radar systems that would force the enemy to carry a large number of complex devices for radar countermeasures on their combat planes and missiles. Therefore, the

development of radar countermeasure devices stipulates a proportionate development of devices for the defense against these countermeasures. In other words, modern radar installations or radar systems necessitate the application of an ever increasing and in-principle different devices used for defense against countermeasures, for it is only in this way that the effectiveness of enemy countermeasures and hence the momentary or permanent disablement of the installation can be minimal. Noncomplex radar systems or installations can totally be thrown out of commission by simple countermeasures.

Quick and effective electronic defense measures on radar installations or systems require topnotch training of the operator and very thorough knowledge of the ways of finding radar installations and systems as well as all kinds of countermeasures and their effects.

Radar countermeasures can be divided into several groups depending on their effects; these groups can in turn again be intentionally or accidentally combined. The less trained the user of an installation is, the more effective will be the countermeasures.

As can be seen from Fig. 7.1, radar countermeasures are basically divided into:

- intentional, the purpose of which is to put out of commission the particular radar installation or system, and
- accidental, which are the result of close operation of several radio installations or the effect of location, site facilities, or meteorological conditions.

Relative to the effects which are achieved, the intentional radar countermeasures are divided into:

- measures with the masking effect, where either by active or by passive means certain parts of radar screen are covered for the sake of concealing or masking of true targets. The masking can be either coarse (noticeable covering of a part of or the entire surface of the indicator screen) or discrete (surrounding of the true target by a large number of false echoes in which the true target is lost);

- measures with the confusion effect, i.e. the creation of such an effect on a radar indicator which is very similar to the symptoms which produce malfunction of the installation. Its purpose is to convince the user that a malfunction occurred on the installation, as a result of which he should as soon as possible switch it off and get it "repaired;"

- measures with the imitation effect, i.e. the creation of false echoes within the vicinity of the true echoes, with the same electrical characteristics, for the purpose of directing enemy measures towards the direction of false echoes;

- changing target coordinates, i.e. by creation of the false echo together with successive change in the coordinates in the direction of the enemy its countermeasures are directed into the void;

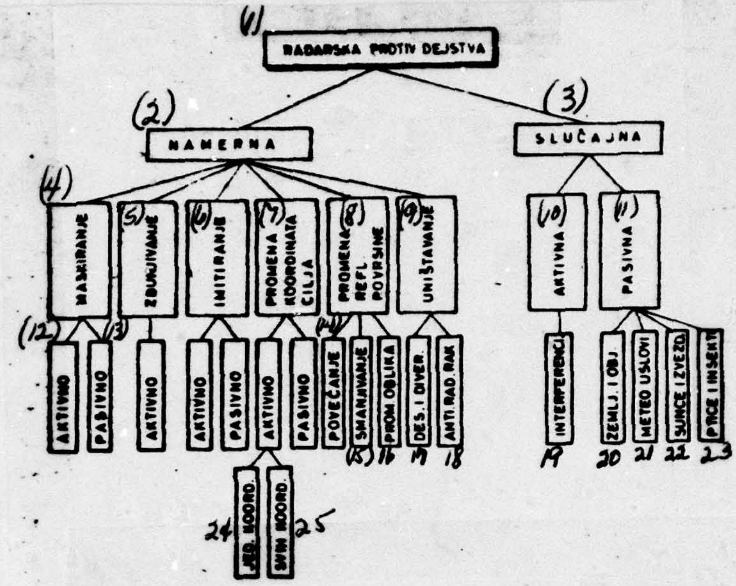


Fig. 7.1. Systematization of radar countermeasures with respect to effect.

Key: (1) Radar countermeasures; (2) Intentional; (3) Accidental; (4) Masking, (5) Confusion; (6) Imitation; (7) Changing target coordinates, (8) Changing REFL surface; (9) Destruction; (10) Active, (11) Passive, (12) Active; (13) Passive; (14) Increase; (15) Decrease; (16) Changing shape; (17) Landing and diver.; (18) Antiradar Rocket, (19) Interference; (20) Site [terrain] and facilities, (21) Meteor. cond.; (22) Sun and stars; (23) Birds and insects, (24) One coord, (25) All coord.

- changing reflex surface - By the application of the respective greases, coatings, or passive reflectors, the reflex surfaces of the target can be decreased or increased. For instance, a bomber gives off the echo of a fighter plane, a boat gives the echo of a destroyer, and the like. By suitable selection and/or combination of the reflector and the grease, the echoes of salient objects of ground configuration can be totally changed;

- destruction - Understood here is the physical destruction of the installation by one of the known methods (airplane attack, military landing, diversion, antiradar rockets, and similar).

7.1. ACCIDENTAL RADAR COUNTERMEASURES

In addition to useful (intelligent) signals (i.e. echoes from the object observed), the input of a very sensitive radar receiver intercepts also various undesirable signals, such as may be caused by reflection of the energy from objects on the ground, terrain configuration, vegetation, clouds, precipitation, birds, and similar, or by various sources of radiation in the universe. All these signals show up on the radar indicator screen, depending on their nature, by increased noise level, false echoes, covered surfaces on the indicator, or increased attenuation on the radar--target--radar relationship.

Which source of accidental signals represents harmful signals in the given case depends on the purpose of the radar installation. Thus, for a ground radar, whose purpose it is to search the air space, the signals reflected from the terrain and meteorological phenomena are

interfering signals. On the other hand, in the case of ship radar, reconnaissance plane radar, or coastal radar, echoes from the terrain or objects on it are of primary significance. In case of a meteorological radar the indication of meteorological phenomina is a useful signal, everything else is useless.

Similar interferences - namely, such as are due to their daily presence, chaotic behavior, and their mutually added up vector effect - have a tremendous effect on daily disablement of the radar installation. This is great attention has been given to these countermeasures up to the present day. In the early years of the development of radar technology, various techniques for cancellation of permanent echoes have been developed (MTI, ATI, AMTI), in addition to various pulse discriminators and time restrictors, as well techniques for utilizing the variable polarization of antenna beam (in case of meteorological phenomena). All these methods were at the given time rather effective. Since today, on the one hand, the targets have decreased and the range has increased (radars with large ranging) and, on the other hand, the targets have been mixed with permanent echoes (exposure of low-flying aircraft, vehicles or pedestrians in the woods, small boats on the churned-up seas), new methods have been developed based on the principles of statistical treatment of radar data, long-term comparisons, and discretization in all the elements (amplitudes, frequencies, signal phases), as also prolonged integrated display of the target.

In case that radar or other electronic installations operate at a small distance from each other, and certainly if they operate at near or similar frequencies, mutual interferences appear in the

form of disturbances. Depending on their interrelationship and nature of the installations these disturbances can be of the pulse type, nonsynchronized, or continual, with their peculiar modulations. The effect which emerges in this case shows up on the indicator and is entirely similar to the effect attained in case of the application of intentional countermeasures of the corresponding kind (see Fig. 8.6). By analogy, neither do the measures of defense differ.

7.1.1. INFLUENCE OF THE TERRAIN

The terrain, its configuration, artificial creations, trees, vegetation, agricultural products (especially the tall ones), and similar, represent objects on which the energy is reflected from when "illuminated" by radar beam to a greater or lesser degree; when this energy arrives at the radar receiver it becomes mixed with the signals from the true target. When attempting to expose objects such as an airplane flying over the terrain, a ship on churned-up sea, vehicles in the woods, pedestrians in the shrubbery, and similar, these echoes from ground objects make their exposure more difficult and in some cases even impossible.

The reflecting surface of the objects of ground configuration has an extremely complex form. If it is not covered by high vegetation and if there is no movement between the energy source and the reflecting objects, the reflected energy fluctuates but little. In regard to the formation of an echo, much more complex are forest objects, shrubbery, bushes, complex equal vegetation, and similar. The reflex surface of these objects consists of the immovable (trunk) and the slightly movable parts (branches, leaves, stalks, grass, and similar),

which move randomly (chaotically) under the effect of the wind. Because of this, the echo from such objects is made up of a permanent component which has all the characteristics of an immovable target, and a component which strongly fluctuates in amplitude and phase and which has all the characteristics of a movable target. The ratio between the "movable" and the "immovable" component depends on the nature of the object, wavelength of radar receiver, pulse frequency, and climatic or meteorological conditions. For instance, the echo from a wooded hill in case of a wavelength of 9.4 cm and wind velocity 28 km/h represents a slightly fluctuating signal, at the velocity of 37 km/h the fluctuation rapidly increases, and at a velocity of 80 km/h the fluctuation of the echo is already such that it has all the components of the movable target.

Figure 7.2 shows the fluctuation in the amplitude of the receiving signal from a wooded hill during a time of 1.5 seconds and at wind velocity of 37 km/h.

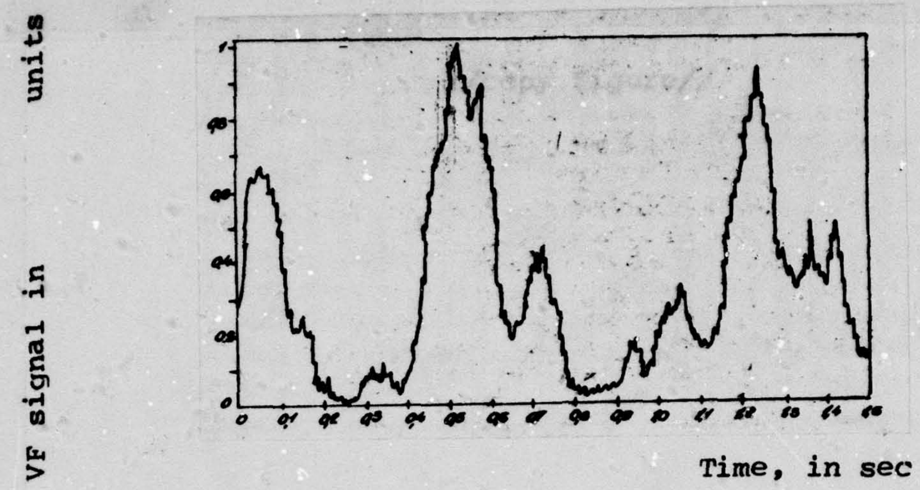


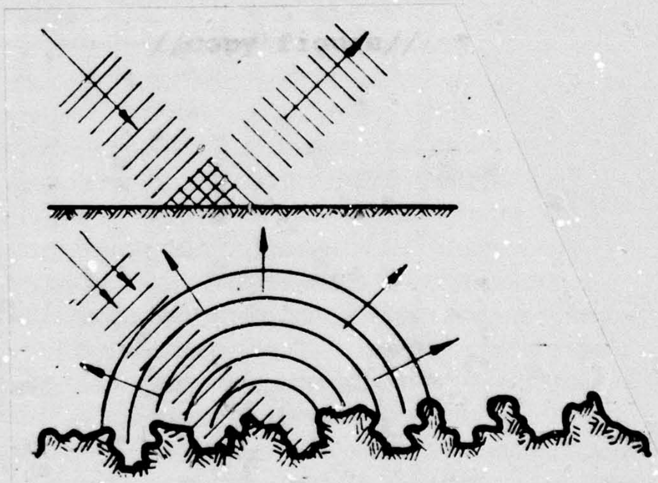
Fig. 7.2. Amplitude fluctuation of the echo from a wooded hill (λ = 9.2 cm, v = 37 km/h)

The tests which were at one time performed by Goldstein confirmed that this fluctuation is caused by the movement of the elements of the reflex surface under the influence of the wind, for wavelengths smaller than one quarter. This is logical, since with decreased wavelength the smaller elements (leaves, grass, stalks) which are under the influence of the wind are almost always mobile and hence acquire ever increasing reflection properties. With decreased pulse frequency, the "mobile" component is even more pronounced due to the longer time which elapses between two neighboring pulses.

The terrain as an echo of the surfaces represents a complex surface-ordered target under radar illumination, such as introduces disturbances

in the radar receiving signal in proportion to the quality and quantity of surface illumination. If the terrain is flat, the reflection in the direction of the receiver will be smaller or none at all, as long as the energy is reflected in all directions in the intersected terrain, as a result of which more energy reaches the receiver. This phenomenon is illustrated in Fig. 7.3.

The terrain surface which shall be illuminated primarily depends on the width of the antenna beam and the duration of the pulse. The secondary dependence exists in regard to the type of radar used and its radiation diagram. Finally, the illumination surface depends



a

b

Fig. 7.3. Reflection from the terrain: a -- flat, b -- intersected

also on the installation proper of the radar installation. Generally, the effect of the reflected energy from the terrain increases with increased energy which is radiated towards the terrain (true for all search radars, especially those used for low-flying targets, but also applicable to ship-, coastal, and anti-mortar radars, etc.). Although in all such radars one tends to have the energy which is radiated toward the terrain as minimal, radiation cannot be avoided,

and as a result of this an interfering (disturbing) signal appears.

As a simple case of illumination geometry of the terrain is taken the case when radar antenna is at a height h. The terrain is illuminated under an angle Φ with azimuthal beam width $\Delta\beta$ and elevation beam width $\Delta\varepsilon$.

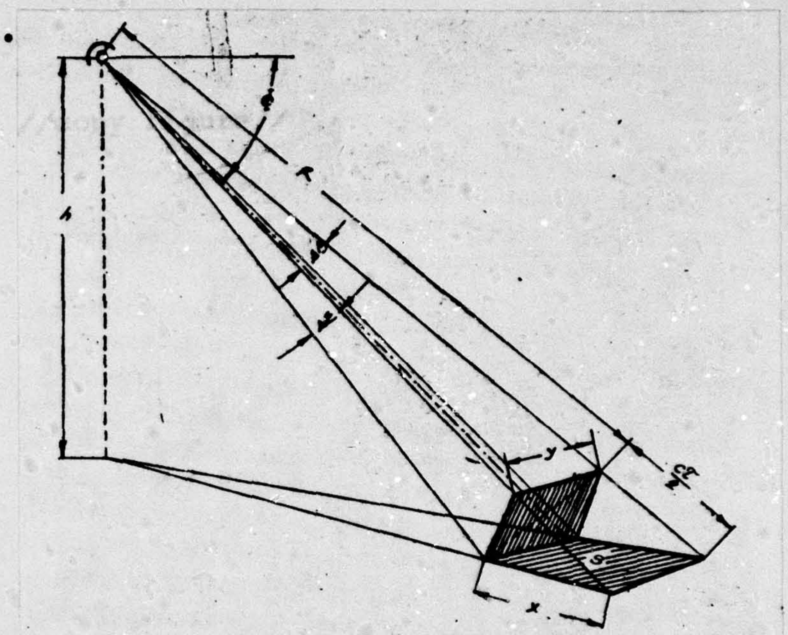


Fig. 7.4. Illumination geometry of the terrain by an antenna erected at height h.

On the basis of geometrical relationships we obtain for

$$x = \frac{c \cdot \tau}{2} \cos\left(\Phi - \frac{\Delta\varepsilon}{2}\right)$$

$$y = \frac{\pi}{180^\circ} \cdot \Delta\beta \cdot R$$

The illuminated surface is

$$S = x \cdot y = R \cdot \frac{\pi \cdot c \cdot \tau}{360^\circ} \cdot \Delta\beta \cdot \cos\left(\Phi - \frac{\Delta\varepsilon}{2}\right) \qquad (7.1)$$

where: S = illuminated surface in [m^2]

c = velocity of light = [$300 \cdot 10^6$ m/sec]

τ = duration of radar pulse in [sec]

R = distance in [m] .

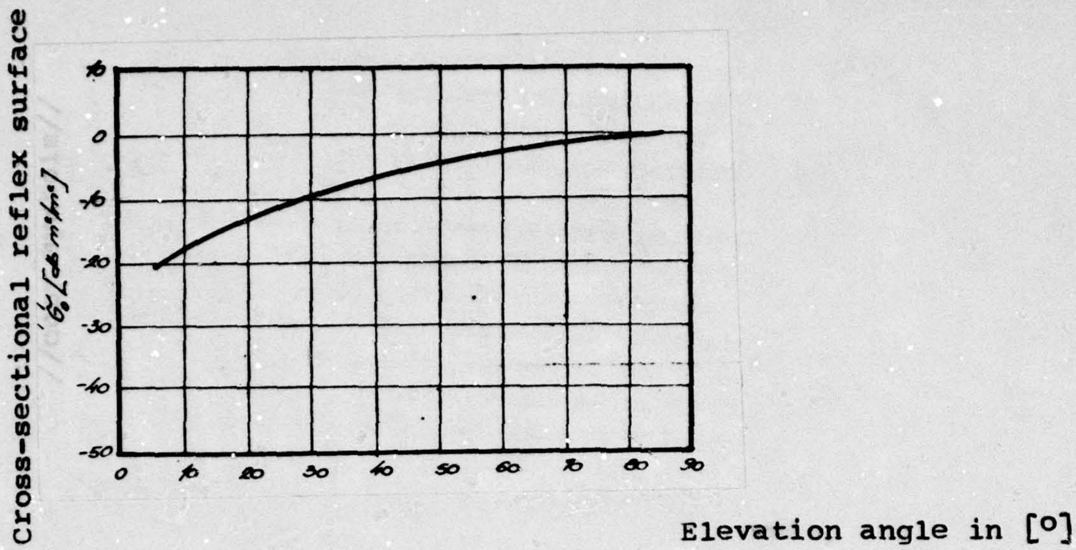


Fig. 7.5. Dependence of cross-sectional surface of a forest massif having trees approximately 15 m in height.

For true targets above earth's surface to be visible, the target signal must be at least equal to, but generally by 2-3 times larger than the disturbance (interference) signal. This relationship is known as <u>radar contrast</u> and is equal to

$$K_{contr} = \frac{\sigma_{ef} \cdot \text{of target}}{\sigma_0 \cdot S} \leq 2\text{-}3 \qquad \ldots\ldots \quad (7.2)$$

where: σ_{ef} of the target = effective radar reflex surface of the target in $[m^2]$;

σ_0 = specific radar reflex surface of the terrain in $[m^2/m^2]$;

S = surface of the terrain illuminated by antenna beam in $[m^2]$.

The specific radar reflex surface for all kinds of terrain is determined experimentally.

Figure 7.5 shows the dependence of cross-sectional reflex surface of a forest massif on angle of incidence, expressed in $[db\ m^2/m^2)$.

Transformation of the units is done according to the sample

$$\sigma_{[dbm^2]} = 10 \log \sigma_{[m^2]}$$

7.1.2. EFFECT OF SEA SURFACE

The energy reflected from the sea surface can seriously endanger or even prevent the detection of targets located on this surface or just above it. The interfering signals from the sea surface are caused by all the surface elements inside the dissociation parameter of the radar. The magnitude of this surface depends on the depression angle, the width of the antenna beam, and the duration of the pulse, all of them in dependence on the distance. Therefore, for the radar reflex surface of the sea surface it is again convenient to take the specific radar reflex surface in m^2 per 1 m^2 of the surface.

The reflex surface of the entire illuminated surface thus amounts to

$$\sigma = \sigma_0 \cdot S \; [m^2] \qquad \ldots\ldots \quad (7.3)$$

where: σ_0 = specific reflex surface in $[m^2/m^2]$ and

S = illuminated surface in $[m^2]$.

For the installation with pulse duration τ, azimuthal beam width $\Delta\beta$ and depression angle Φ, at a distance R, we obtain for the illuminated surface (from illumination geometry in Fig. 7.4) the following:

$$S = R \cdot \frac{\pi \cdot c \cdot \tau}{360^\circ} \cdot \Delta\beta \cdot \cos\Phi \; [m^2] \qquad \ldots\ldots \quad (7.4)$$

Since for small depression angles Φ, which is the case for coastal and ship radars, $\cos\Phi \approx 1$, then the equation (7.4) acquires the form

$$S = R \, \frac{\pi \cdot c \cdot \tau}{360^\circ} \cdot \Delta\beta \cdot [m^2] \qquad \ldots\ldots \; (7.5)$$

where: R = distance in [m]

c = velocity of light in [m/sec]

τ = duration of the pulse in [sec]

$\Delta\beta$ = azimuthal beam width in [°].

The characteristics of the reflected signal from sea surface depends not only on the illuminated surface, but also on the following parameters, namely: depression angle, polarization of the emitted wave, operating frequency, and "state of the sea." The latter parameter encompasses all the factors affecting the shape of the surface, such as the shape of the churning up, the wind (velocity and direction), the currents situation, and the like. It is not the

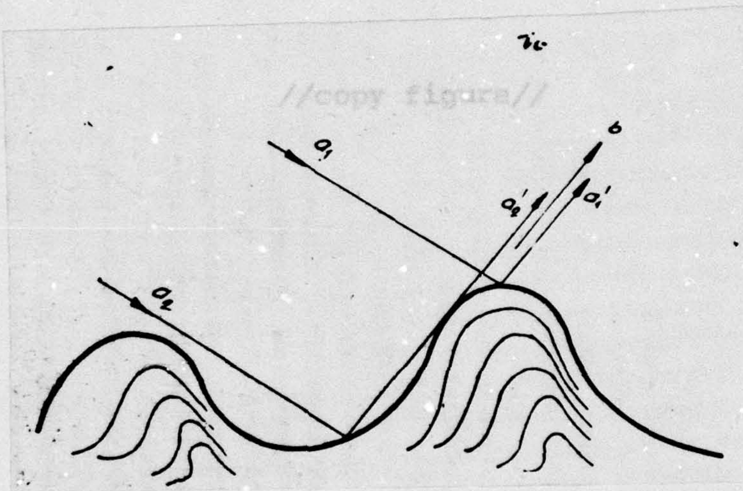


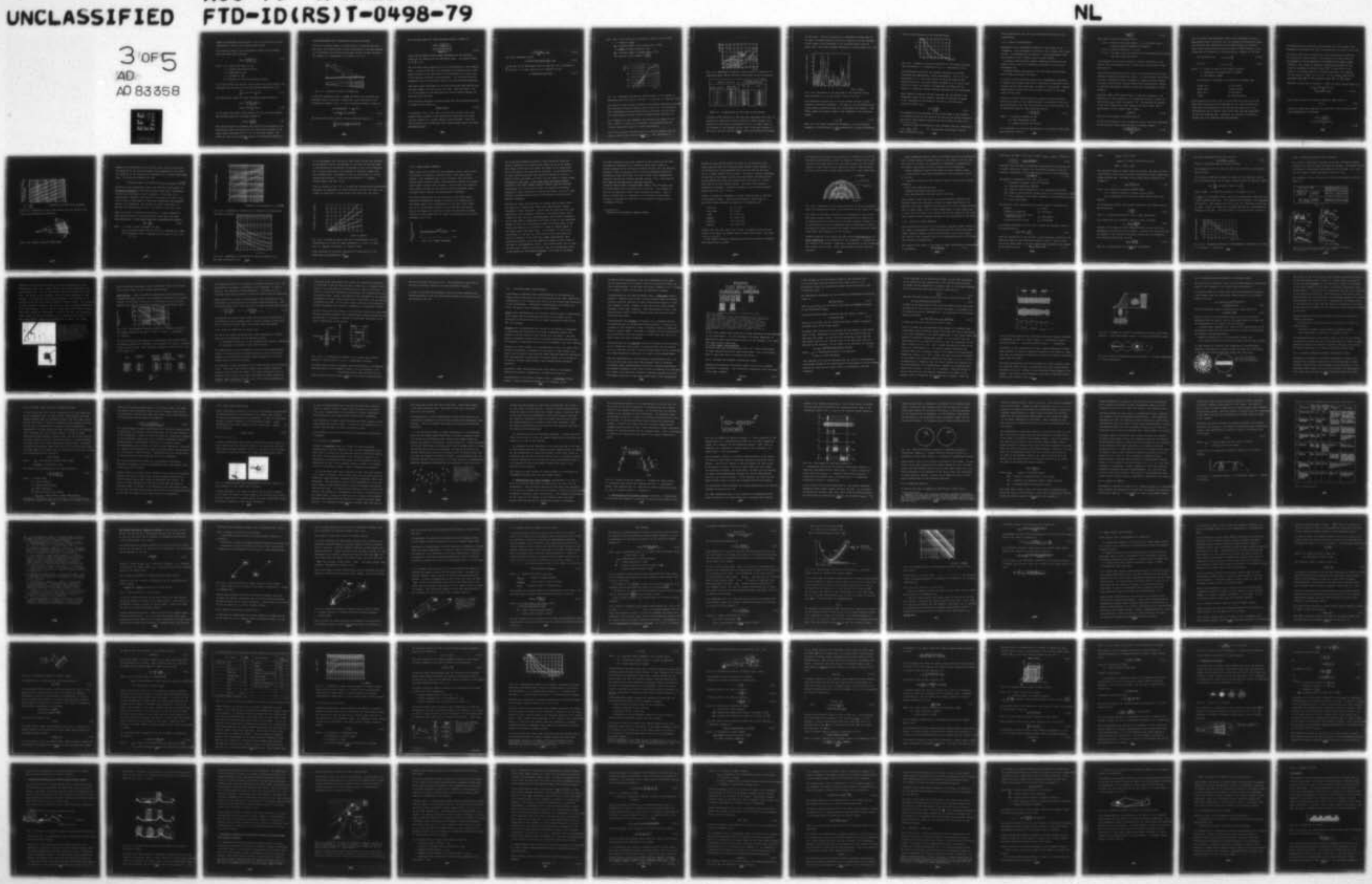
Fig. 7. 6. The possible geometry of the reflection from sea surface; a_1, a_2 represent the incoming wave; a_1', a_2' represent the wave reflected from a_1 and a_2; b represents the sum of the reflected wave from a_2 and a_1.

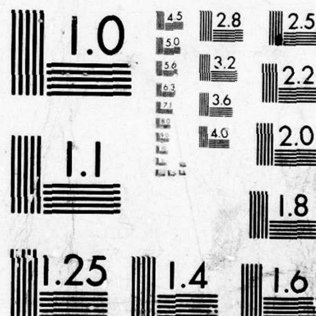
height of the wave that is essential for the creation of interference, but rather its shape and velocity of motion. Thus, the largest interference is caused by waves created by a storm, whereas waves caused by the south wind create a smaller interference signal, even though they may be higher. On the contrary, long waves can affect the formation of the radiation diagram, i.e. its fanlike structure. The mechanism of this phenomenon is explained in Fig. 7.6.

Because of this the sea surface represents with respect to its reflecting properties a superficially large object, with a large

AD-A083 358 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/4
ELECTRONIC COUNTERMEASURES,(U)
AUG 79 A RAZINGAR
UNCLASSIFIED FTD-ID(RS)T-0498-79 NL

3 OF 5
AD
A083358





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

number of individual reflex surfaces (σi), each of which by itself independently reflects the incoming radar energy.

The receiving energy of the interference signal can be obtained using the known radar equation

$$P_{prij,om} = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \cdot \sum_{i=1}^{n} \sigma_i \qquad (7.6)$$

where: Pi = radar pulse power in [W]

G = antenna amplification factor

λ = wavelength in [m]

R = distance in [m]

σi = particle of the reflex surface in [m^2]

If by σo we define the specific reflex surface per unit surface, the expression for the sum of the reflex surfaces acquires the form

$$\sum_{i=1}^{n} \sigma_i = \sigma_0 \cdot S = \sigma_0 \cdot R \cdot \frac{\pi \cdot c \cdot \tau}{360} \cdot \Delta\beta \qquad (7.7)$$

The interference signal for small depression angles amounts to

$$P_{prij,om} = \frac{P_t \cdot G^2 \cdot \lambda^2 \cdot c \cdot \tau \cdot \Delta\beta}{64 \cdot \pi^2 \cdot R^3 \cdot 360^0} \cdot \sigma_0 =$$

$$= 1.295 \cdot 10^3 \cdot \frac{P_t \cdot G^2 \cdot \lambda^2 \cdot \tau \cdot \Delta\beta}{R^3} \cdot \sigma_0 \qquad (7.8)$$

If the target with radar reflex surface σ is at the same distance, the receiving power of its signal amounts to

$$P_{prij,cilja} = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \qquad (7.9)$$

When both equations are compared, one sees that the strength of the interference signal decreases with R^3, whereas the strength of the target signal decreases with R^4, i.e. by one power faster. The reason for this is the geometric nature of illumination whereby by

increased distance the illuminated sea surface increases.

In case of airplane radars or radars which are situated high above sea level, the surface which is being illuminated by the beam depends on its azimuthal and elevation width more so than on pulse duration. The geometry of illumination is as shown in Fig. 7.7.

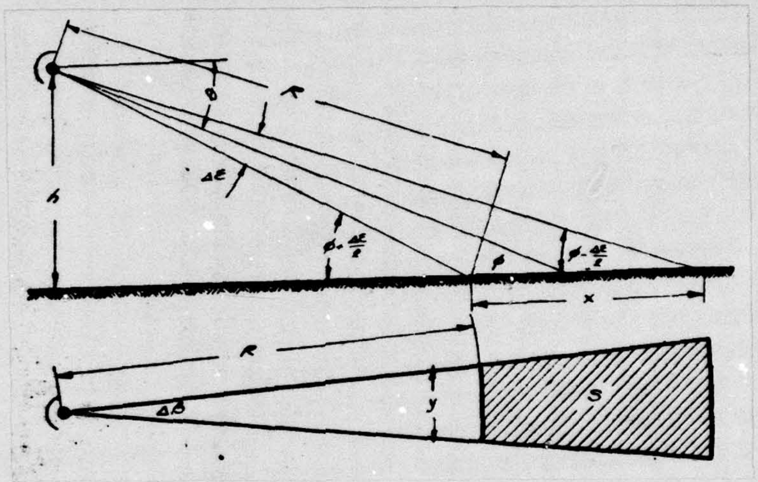


Fig. 7.7. Geometry of surface illumination

If Φ is the depression angle, and $\Delta\varepsilon$ and $\Delta\beta$ are the elevation and azimuthal width of the beam, respectively, then according to the illumination geometry (Fig. 7.7) the illuminated surface is equal to

$$x = 2R \sin\Phi \sin\frac{\Delta\varepsilon}{2}; \quad y = \frac{\pi}{180}\,\Delta\beta\cdot R$$

$$S = 2R^2\frac{\pi}{180}\cdot\Delta\beta\cdot\sin\Phi\sin\frac{\Delta\varepsilon}{2} \tag{7.10}$$

The total radar reflex surface of the illuminated surface is

$$\sum_{i=1}^{n}\sigma_i = \sigma_0\cdot S = \sigma_0\cdot R^2\frac{\pi}{90}\cdot\Delta\beta\cdot\sin\Phi\sin\frac{\Delta\varepsilon}{2} \tag{7.11}$$

The receiving signal for large depression angles is equal to

$$P_{sprej,om} = \frac{P_t \cdot G^2 \cdot \lambda^2}{(4\pi)^3 R^4} \sum \sigma_i = \frac{P_t \cdot G^2 \cdot \lambda^2 \cdot \Delta\beta \cdot \sin\Phi \cdot \sin\dfrac{\Delta\varepsilon}{2}}{5760 \cdot \pi^2 \cdot R^3} \tag{7.12}$$

This equation shows an even greater dependence of the receíving signal on the distance and the depression angle. The maximum signal is at $\Phi = 90^\circ$.

The reflected signal depends also on the polarization of the incoming wave. In case of calm sea, the horizontal polarization gives a much smaller signal of the reflection in the direction of the radar than is the case for vertically polarized beam. With increased wave and depression angle the difference between the polarizatuons disappears.

Tests have shown differences in the reflected signal when observations are done against the wind or with the wind. Thus the signal is by 5 to 10 db higher in the observation of the sea surface against the wind than with the wind.

The visibility condition of target signal over the interference which is caused by sea surface is

$$P_{sprej,cilja} \geqslant P_{sprej,om} \tag{7.13}$$

If equations (7.8), (7.9), and (7.12) are put in form (7.13), the minimal reflex surface of the target can be found which the radar can still detect at a certain specific reflex surface. Thus, the reflex surface for the smallest still visible target σ_c is, for small depression angles

$$\sigma_c = \frac{R \cdot c \cdot \tau \cdot \Delta\beta}{360} \cdot \sigma_0 \cdot \cdot [m^2] \qquad (7.14);$$

for large depression angles

$$\sigma_c = 3{,}454 \cdot 10^{-8} \cdot R^2 \cdot \Delta\beta \cdot \sin\Phi \cdot \sin\frac{\Delta\varepsilon}{2}\, \sigma_0 \cdot \cdot [m^2] \qquad (7.15)$$

If the sine of the depression angle in equation 7.15 is replaced by $\frac{h}{R}$ (see Fig. 7.7), then equation (7.15) assumes the form

$$\sigma_c = 3{,}454 \cdot 10^{-8} \cdot R \cdot h \cdot \Delta\beta \cdot \sin\frac{\Delta\varepsilon}{2}\, \sigma_0 \qquad (7.16)$$

where: σ_c = reflex surface os the smallest visible target in [m],

R = distance in [m],

$\Delta\beta$ = azimuthal width of the antenna beam in [°],

h = height of radar antenna in [m],

$\Delta\varepsilon$ = elevation width of antenna beam in [°],

σ_0 = specific reflex surface in $\left[\frac{m^2}{m^2}\right]$.

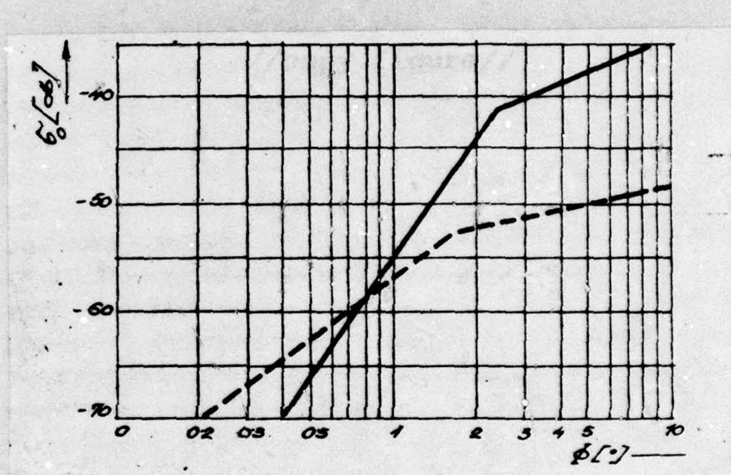


Fig. 7.8. Dependence of specific reflex surface of sea surface on depression angle and state of the sea: 1 - calm sea, 2 - moderate waves.

The specific reflex surface increases with increased depression angle Φ. This increase follows the dashed curve in Fig. 7.8. The depression angle subtending the inflection point is called the critical angle. Its characteristic feature is that increased waving decreases it.

The "roughness" of sea surface is determined by the height of the wave. Table 7.1 shows its international categorization and the critical depression angle for various wavelengths.

One of the important characteristics of reflected signals from sea waves is their highly random fluctuation. This fluctuation is

//copy figure//

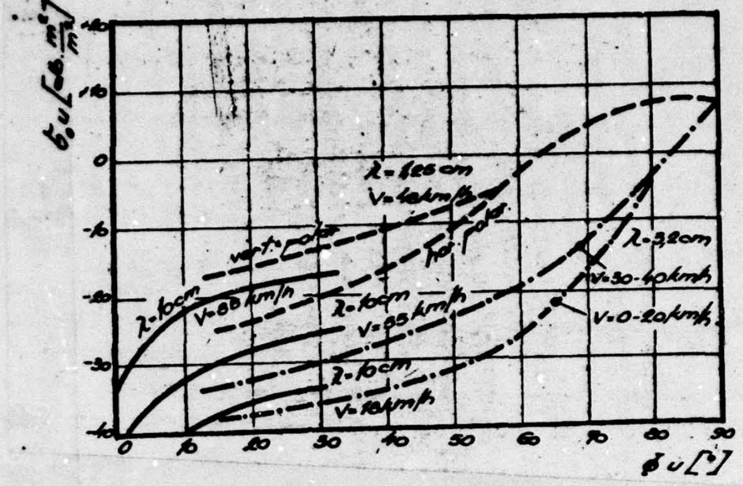


Fig. 7.9. Dependence of specific reflex surface of the sea δ_0 on depression angle Φ for different wavelengths and wind velocities

State of the sea		Critical angle 2 [°] at wavelength λ [cm]	
degree (balli)	mean wave height (m)	10	3
1	0,15	4,7	1,4
2	0,45	1,6	0,47
3	0,9	0,8	0,24
4	1,8	0,4	0,12
5	3,2	0,22	0,07
6	5,	0,14	0,04
7	7,6	0,095	0,03

Table 7.1. Categorization of the state of sea surface.

affected by the direction of the wind and, associated with this, by direction of motion of the wave relative to radar station (i.e. whether the radar beam is perpendicular or at a certain angle to the incoming or the outgoing waves), size of the wave, margin at the top of the wave and the droplet cloud which washes the breaking

of each wave. That the fluctuation is considerably higher than in the case of ground echoes can be seen by comparing the time diagrams of the change in the amplitude of the receiving signal from sea waves (Fig. 7.10) with analogous diagrams for ground echoes (Fig. 7.2).

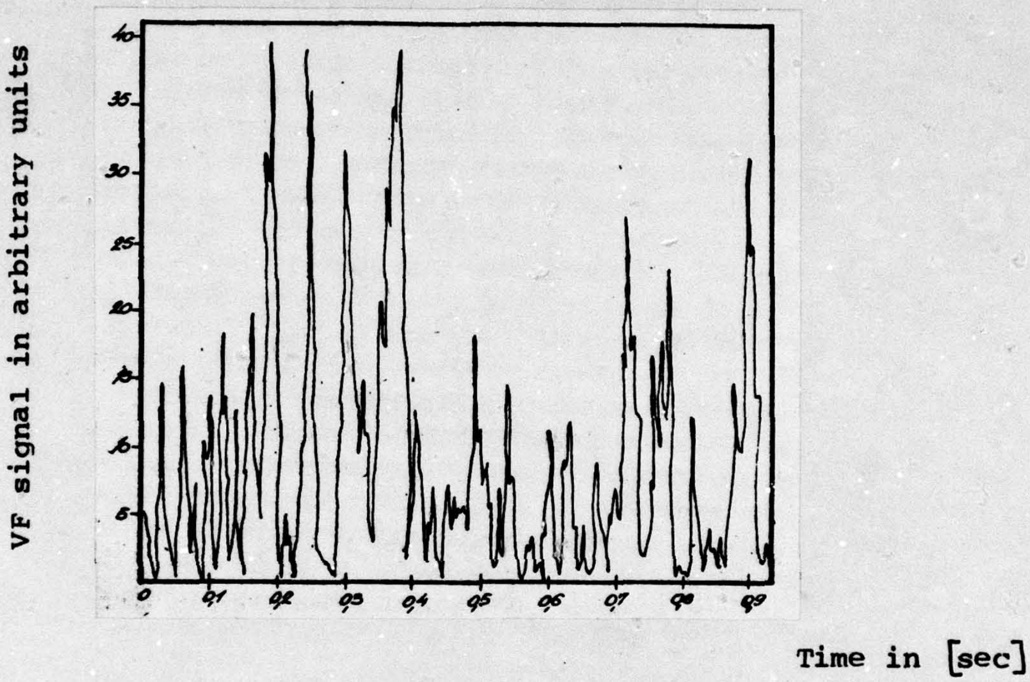


Fig. 7.10. Fluctuation in the amplitude of the receiving signal from sea waves at $\lambda = 9.2$ cm during a time of 0.9 sec.

The interference signals due to the sea surface include a marked frequency fluctuation component. Its cause is the continuous motion of sea surface particles inside the illuminated radar surface. This motion causes the Doppler change in the frequency of the receiving signal.

$$f = f_0 + \frac{2v}{\lambda} \qquad (7.17)$$

where f_0 is the radar transmitting frequency, v is wave velocity component in the direction of the observation, λ is radar wavelength,

and f is the frequency of the reflected signal.

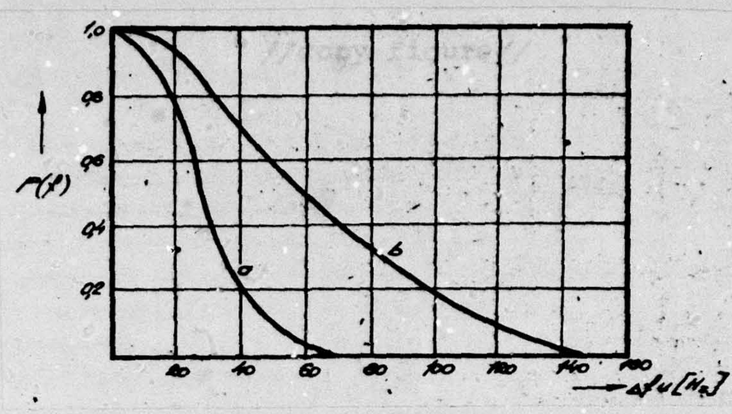


Fig. 7.11. Frequency fluctuation spectrum for the signal reflected from sea surface: a - wavelength 9.2 cm, b - wavelength 3.2 cm.

The measurements show that the frequency spectrum for low wave velocities has approximately Gauss* distribution. For $\lambda = 3.2$ cm, wave height 0.6 m, and wind velocity 15 km/h the width of the spectrum is 82 Hz. With wave height increased to 1.5 m and at wind velocity 26 km/h, the width of the spectrum is already 172 Hz. Figure 7.11 shows the average frequency spectrum for two wavelengths.

Using empirical equation (Hicks's equation) one can determine the approximate width of the frequency spectrum at one-half the power (3 db), depending on the height of the wave H_t and their mean recurrence period (t_{sr})

$$\Delta f \approx \frac{11 \cdot H_t\,[\text{cm}]}{t_{sr}\,[\text{sec}]} \tag{7.18}$$

The advantage of this equation is that on the basis of the measured or estimated values for the state of the sea one can quickly determine the width of the frequency spectrum and on the basis of this, for a

---

*Gauss or normal distribution is most probably given by (expression) $y = \varphi(x) = \frac{1}{\sigma \cdot \sqrt{2\pi}} \cdot e^{-\frac{x^2}{2 \cdot \sigma^2}}$; σ = distribution law parameter and can have an arbitrary value.

given installation, one can at once determine the effect of the interference.

7.1.3. EFFECT OF ATMOSPHERILIA

Atmospherilia are condensation products of water vapor in the atmosphere. They can appear in the form of fog, clouds, rain, snow, or hail. If atmospherilia are present in radar observation zone, they basically have a twofold effect on radar signal:

- by energy reflection they produce undesirable echoes with the masking effect, which with decreased wavelength is all the more pronounced, and
- introduce higher attenuation in the path radar--target--radar and in this way decrease its range.

By virtue of their reflecting properties, atmospherilia represent a complex reflex object made up of a multitude of elementary reflex objects, such as water particles, or snow or ice particles. Spatial distribution of these particles is uniform relative to the pulse volume of the radar.

Since fog, clouds, and precipitation consist of almost spherical particles of water or ice, whose diameter is much smaller than the radar wavelength, the radar reflex surface of a single particle can be determined using the known Rayleigh equation

$$\sigma_i = \frac{\pi^5 \cdot d^6}{\lambda^4} \cdot \left(\frac{n^2 - 1}{n^2 + 1}\right)^2 \qquad (7.19)$$

where: d = particle diameter in [m]

λ = radar wavelength in [m]

n = complex fracture coefficient

If we designate the fraction encompassed by the fracture coefficient from equation (7.19) by

$$K=\left(\frac{n^2-1}{n^2+1}\right)^2 \tag{7.20}$$

then factor K has the following values:

- for λ = 0.8-10 cm and water droplet: K = 0.90-0.92, and is extremely poorly temperature dependent;
- for λ = 0.8-10 cm and ice: K = 0.19;
- for λ = 3 cm the K for ice and snow is by approximately 22% smaller than the K value for water.

From equation 7.19 (or more accurately stated, from factor K) one can see that water droplets have a larger radar reflex surface than snow and ice.

During the precipitation, the dry snow or ice particles melt as they penetrate through the warmer air layers. In this process, the particle is first surrounded by water, whereupon it changes to water droplet. The radar reflex surface changes during this transformation, meaning it increases and finally reaches a value which corresponds to water droplets.

Spherical radar reflex surface σ_0 is in this case obtained by the summation of reflex surfaces of all elementary particles inside the unit volume V_{unit}, which is usually 1 m^3. The magnitude σ_0 depends on the type of particles, their quantity per unit volume, and on polarization of the incoming radar signal.

$$\sigma_0=\Sigma\,\sigma_i\cdot n_i \tag{7.21}$$

where n_i is the number of particles per m^3.

If now we put equation (7.19) in equation (7.21), the final expression for the specific radar reflex surface is obtained, namely:

$$\sigma_0=\frac{\pi^5}{\lambda^4}\cdot\left(\frac{n^2-1}{n^2+1}\right)^2\cdot\sum\sigma_i\cdot n_i \tag{7.22}$$

Due to the fact that expression (7.22) is not convenient for daily applications since it does not use the customary meteorological units, the relations were experimentally determined between the specific radar reflex surface and the amount of water W [g/m^3] present in the clouds and the intensity of the precipitation I [mm/hr] in the form

for clouds and fog $$\sigma_0 = 13{,}2 \cdot 10^{-18} \frac{W^2}{\lambda^4} \qquad (7.23);$$

for rain $$\sigma_0 = 6{,}2 \cdot 10^{-14} \cdot \frac{I^{1,6}}{\lambda^4} \qquad (7.24),$$

where: W = amount of water in the clouds in [g/m^3],

I = intensity of precipitation in [mm/hr],

λ = wavelength in [cm].

With respect to intensity, precipitation is divided into:

slight rain	0.5-5.0 mm/hr,
medium rain	5.0-25.0 mm/hr,
heavy rain	25-125 mm/hr,
shower	125 and more mm/hr.

From equations (7.23 and 7.24) it can be seen that for one and the same radar installation the magnitudes of the reflex surfaces and hence also the intensities of the interfering signal due to the precipitation are by several times larger than the same magnitudes in case of clouds and fog. Therefore, the principal interfering signals are to be expected from precipitation.

The magnitude of the effective reflex surface per unit volume (1 m^3) depending on wavelength and type of precipitation is given in Fig. 7.12.

The actual radar reflex surface for a given pulse-radar is obtained if the specific reflex surface is multiplied by the space which at the distance of the precipitation is occupied by the pulse ("pulse volume"). This volume is obtained if the duration period of the pulse as expressed by distance units $\left(\frac{\tau \cdot c}{2}\right)$ is multiplied by the width of the antenna beam at the distance searched. The geometry of this volume is shown in Fig. 7.13. For the antenna beam having azimuthal width $\Delta\beta$ in [°], elevation width $\Delta\varepsilon$ in [°], pulse duration τ_n [sec] and at distance R in [m], the pulse volume amounts to:

$$V=\frac{\pi}{180}\cdot R\cdot \Delta\beta\cdot\frac{\pi}{180}\cdot R\cdot\Delta\varepsilon\cdot\frac{c\cdot\tau}{2}=$$
$$=4{,}57\cdot 10^4\cdot R^2\cdot\tau\cdot\Delta\varepsilon\cdot\Delta\beta \qquad (7.25)$$

The reflex surface of the space occupied by radar pulse is

$$\sigma=V\cdot\sigma_0 \qquad (7.26)$$

Using the known radar equation, the magnitude of the receiving signal from atmospherilia is obtained:

$$P_{prij\cdot atm}=\frac{P_t\cdot G^2\cdot\lambda^2}{(4\pi)^3\cdot R^4}\cdot\sigma=$$
$$=22\cdot 85\cdot\frac{P_t\cdot G^2\cdot\lambda^2\cdot\tau\cdot\Delta\beta\cdot\Delta\varepsilon}{R^2}\,\sigma_0 \qquad (7.26)$$

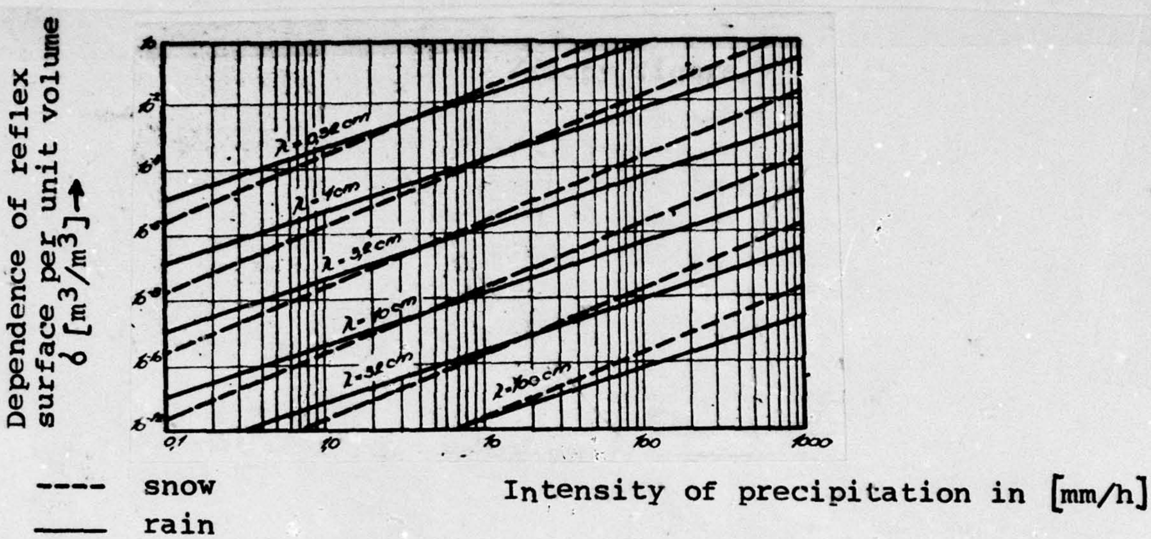


Fig. 7.12. Dependence of the reflex surface per unit volume on the type of precipitation and wavelength

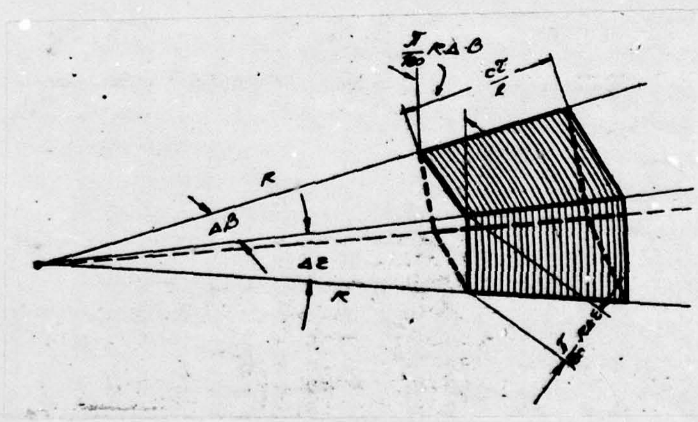


Fig. 7.13. Spatial volume of radar pulse

Comparing the magnitude of the receiving signal from the target with the magnitude of the receiving signal from atmospherilia, the limits of visibility of the target can be determined for a certain pulse-radar type. The visibility condition is that

$$P_{\text{receiving signal from target}} \geqslant P_{\text{receiving signal from atm}} \tag{7.27}$$

Another way that atmospherilia affect the receiving radar signal is <u>increased</u> <u>attenuation</u> on the radar--target--radar path. Attenuation in rain and fog depends on their intensity. In dry snow it is insignificant, whereas in wet snow it is the same as in rain. From 1945 to 1963, a large number of tests and measurements was performed relative to attenuation. The results are given in the form of a diagram, for precipitation in Fig. 7.14, and for fog in Fig. 7.15.

Under the effect of increased attenuation of a radar transmitting and receiving signal on the radar--target--radar path, the radar range decreases. The decreased range can be determined by equation

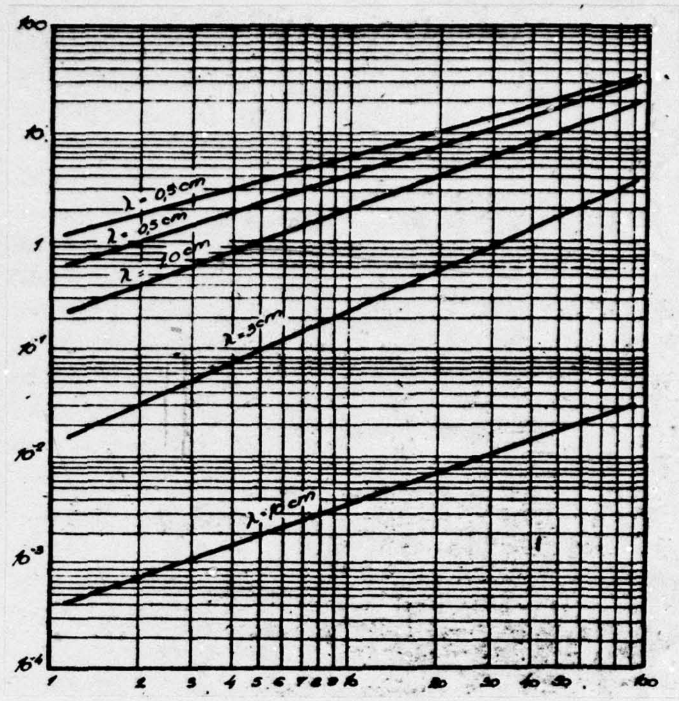
$$R_{atm} = \frac{R}{10^{0.5\beta R}} \tag{7.28}$$

where: R = range in usual atmosphere in [km],

R_{atm} = decreased range under the effect of attenuation in [km],

β = attenuation factor in [db/km] from the graph in Fig. 7.14 or 7.15.

Attenuation β in [db/km] →



Intensity of precipitation M in [mm/h]

Fig. 7.14. Dependence of attenuation on intensity of precipitation and radar wavelength

Attenuation β in [db/km] →

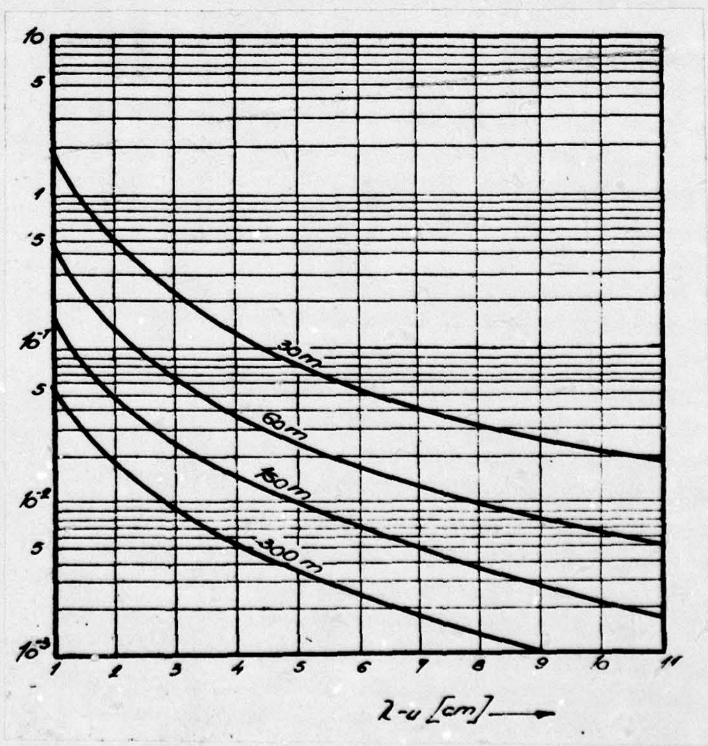


Fig. 7.15. Dependence of attenuation of fog on visibility in m and radar wavelength in cm.

If one presupposes that the entire radar range is under the influence of precipitation and if the decrease in the range for various kinds of precipitation is calculated, the diagram in Fig. 7.16 is obtained for a certain radar type. As an example is selected a radar with the following data: wavelength $\lambda = 3.2$ cm, pulse power Pi = 50 KW, antenna amplification G = 28.6 db, pulse duration $\tau = 0.6 \mu$sec, receiver noise level Nš = 16 db.

From the diagram in Fig. 7.16 it is seen that precipitation significantly decreases the possibility of radar detection and that even light rain (common in Yugoslavia in autumn days) which falls over the entire

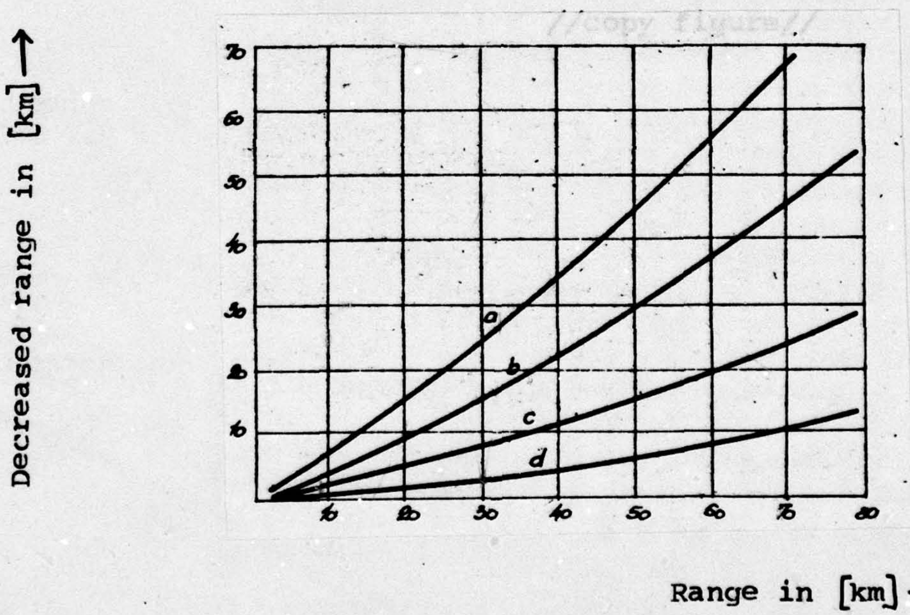


Fig. 7.16. Decrease in radar range due to attentuation from the precipitation (see text for radar parameters): a - dew, b - light rain, c - moderate rain 4mm/h, d - shower 16 mm/h

range decreases the effective possibility of detection of a 3-cm pulse-radar by approximately 40%.

7.1.4. FALSE ECHOES ("ANGELS")

Radar echoes can be caused also by atmosphere parts in which there are present no elements or materials with a true radar reflex surface. This phenomenon has in the literature been called by various names (phantom, ghost, flying sausages), however its latest name "angels" has been most accepted. False echoes have different visual shapes and may be the result of various accidental cases, including birds, insects, and meteorological phenomena.

For radar systems which for the detection of the signal employ statistical methods and automatic systems for the separation of the target signal and for transmission of the data, false echoes are one of the principal causes for the so-called false alarms. This is so because the signal is a false echo which can be summed up with the noise signal and can cross the previously set-up target threshold (Fig. 7.17).

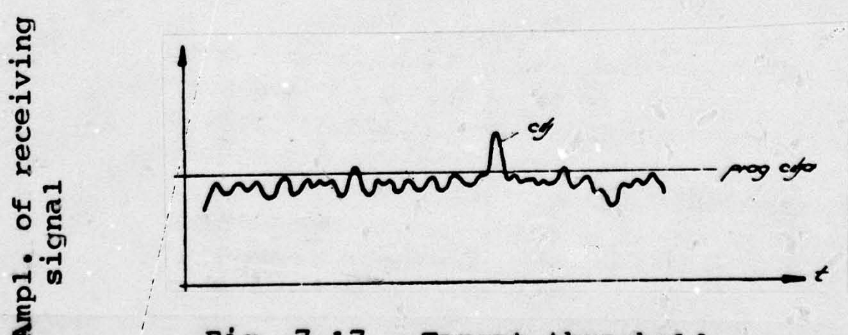


Fig. 7.17. Target threshold

One of the most important sources of false echoes are birds and insects, especially for ground search radars set up at the coast, ship radars which search the coast, and radars of all kinds which are in the path of the migration of the birds. As the sensitivity of radar installations and their detection capability for ever smaller objects increases, the effect of this source of false echoes increases all the time. On the other hand, increased airplane velocities, ever more intense airplane traffic, and ever stricter requirements for flight safety require the display and thorough knowledge of radar echoes due to insects and birds, so as to in time prevent collisions between them and the airplane and thus prevent possible disasters.

Although the radar reflex surface of a single bird is small, when the birds fly in swarms they create very characteristic echoes, certainly at small distances. In this case one gets the effect and specificity of the panoramic indicator of the search radar, which consists in that the vast three-dimensional space which is analyzed by the radar beam is displayed on the small screen in two dimensions. Because of this, the characteristic numerical echoes appear on the screen even when only a few birds or a group of insects appear in the domain within the radar range. For instance, if there is on the average, on the area of 1 km^2 only one bird, then within the area of a radius of 20 km there will appear approximately 1256 reflecting elements, which are capable of forming as many echoes if the beam is correspondingly narrow. Some authors state that if there are more than 8 birds on the area of 1 Nm3, the corresponding parts of the screen will be entirely shadowed. The flight of the birds

and their relatively high speed, especially when carried by the wind, precludes the possibility of eliminating their radar echoes by various systems for the selection of mobile targets (MTI* and similar). Because of this, the birds are one of the more important sources of nonexisting echoes which must as a rule be taken into consideration, especially during the migration periods (spring, fall), and partially when they are the most active (morning, evening).

In case of search radar of medium power (about 1 MW) the echoes from the birds appear also at distances up to 30-40 km. The strength of the echo increases with their flight altitude and number. Thus, a bird of average size at a distance of 15 km creates an echo whose strength is equivalent to the echo of an airplane of average size at a distance of 80 km.

---

*Selection on the basis of Doppler effect.

Testing of radar reflex surfaces of birds in the centimeter wave range confirmed that the reflected signal appears mostly because of the reflection of electromagnetic waves from the body of the bird, and to a lesser degree from the wings. The largely aquaeus composition of the body of the birds, as well as its biological features and its correct geometrical shape make possible the reflecting of a little more than 70% of the incoming energy. The rest of the energy is scattered by feathers. Dielectric constant of the feathers measured within this bulk is $\varepsilon = 1.34$.**

Figure 7.18 shows the dependence of radar reflex surface of the bird on illumination angle. Radar reflex surfaces of some birds, in particular those encountered frequently in Yugoslavia, are:

sea gulls	$\sigma = 0.1\ m^2$;
wild geese	$\sigma = 0.2\ m^2$
crows	$\sigma = 8 \cdot 10^{-3}\ m^2$
pigeon	$\sigma = 5 \cdot 10^{-3}\ m^2$;
starling	$\sigma = 5 \cdot 10^{-4}\ m^2$;
sparrow	$\sigma = 1 \cdot 10^{-4}\ m^2$.

Insects even when very small and if there is enough of them per unit volume of the space can produce rather strong false echoes. The order

---

**For further reference regarding the effect of dielectric constant (see point 10.2.1, p. 265).

of magnitude of the radar reflex surface of a common fly is 10^{-5} m^2. The insects are generally present in groups or "clouds" and they are carried by the wind, which is why one should expect that the motion velocity of the echoes from the insects is equal to wind velocity. In case of large insect clouds, which envelop the entire radar beam,

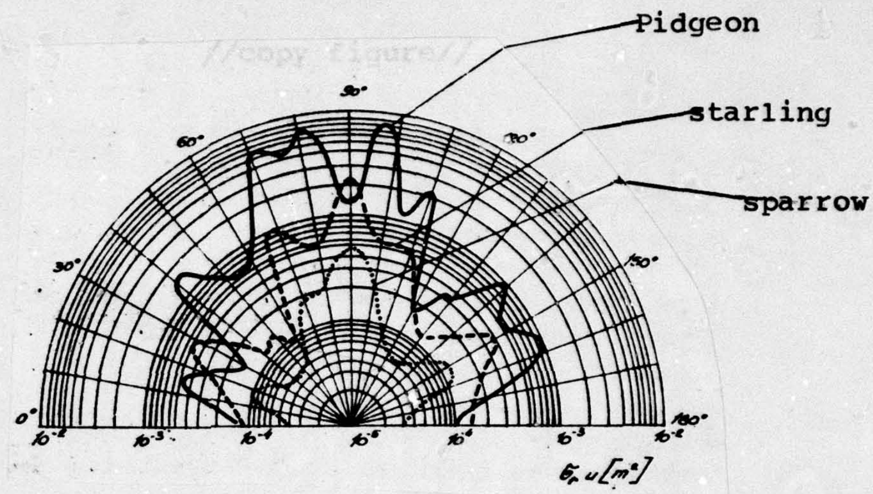


Fig. 7.18. Dependence of the reflex surface of the bird on azimuthal angle of illumination relative to the direction of the flight (0^o - 180^o)

the result is increased attenuation of electromagnetic waves on the path radar--target--radar. The echo phenomenon due to insects can be expected only at a certain time of the day (morning, evening), at low altitudes and at the corresponding ambient temperature (10-30^{o}C) and higher on radars with narrow low beams, shorter wavelength, higher output power and sensitivity of the receiver.

Frequent causes of false echoes are also various heterogeneities and sharp transitions in the properties of the atmosphere. Included here are changes in the density, temperature, and moisture of the atmosphere, dust clouds, and the like. Thus, false echoes can result from the following:

- sharp boundaries between normal, very warmed up and humid atmospheres, such as appear during the summer months, in the middle of the day, and when there is no wind. The dimensions of atmospheric nonhomogeneity can measure from several meters to several tens of kilometers;
- highly pronounced thermal flows below and above cumulus clouds;
- strong thermal flows above nonhomogeneous terrain strongly heated by the sun;
- hurricane whirling in which there is usually lots of dust (flying sausages);
- smoke above complexes on fire;
- unusually increased refraction factor;
- echo manifestations from side fans of the radar.

False echoes of this type have a very characteristic intensity, and therefore should not represent a problem in being identified by the observer; they have a specific form and are, as a rule, of short duration and at a small range. Only if false echoes apper in large amounts and if they cover the entire or the greater part of the indicator, only then there occurs a larger temporary decrease in the performance of the radar.

7.1.5. EFFECT OF COSMIC RADIATION

With increased sensitivity of the receivers, especially radar receivers, the cosmic electromagnetic radiation has become the interfering signal. Cosmic radiation appears also on radar screens in the form of noise; they add up to the intrinsic noise of the installation and in the extreme case decrease its sensitivity.

The tension of the noise at the output of radar installation is determined by expression:

$$\mu_s^2 = 4 \cdot K \cdot T_0 \cdot R \cdot \Delta f \qquad (7.29)$$

From this, the power of the noise signal ($P_{noise,\ instal.}$) amounts to

$$P_{\check{s},\text{vnút}} = 4K \cdot T_0 \cdot \Delta f \tag{7.30}$$

Regarding that the noise of individual installations is characterized by noise coefficient (knoise), the relationship between it and the effective temperature of the installation is given by the expression

$$T_p = T_0 (K_{\check{s}} - 1) \tag{7.31}$$

The symbols in equations (7.29, 7.30, 7.31) are:

K = Boltzman's constant $1.380 \cdot 10^{-23}$ [J/K°],

T_o = absolute temperature [291°K],

T_p = effective noise temperature of the installation in [°K],

Δf = width of the permeable circumference of the installation in [Hz],

R = real component of the output impedance of the installation, and

$k_{\check{s}}$ = noise coefficient.

The effective noise temperatures for various kinds of receivers are:

masers:	T_p = 50°K
parametric amplifiers	T_p = 100-600°K
VF-amplifier with tubes with traveling waves:	T_p = 600-1500°K
VF-amplifier with triode:	T_p = 900-2700°K

By averaging equations 7.31 and 7.30 we obtain the intrinsic noise of the installation as

$$P_{\check{s},\text{vnút}} = 4k \cdot \Delta f \cdot \frac{T_p}{(k_{\check{s}} - 1)} \tag{7.32}$$

Since the sensitivity of the receiver is simultaneously affected by the intrinsic noise and the extraneous sources of noise - which in this case means cosmic noise - the total noise which is limiting the display of the target will be:

$$P_{\check{s}um.\,uk} = P_{\check{s},\text{vnút.}} + P_{\check{s},\text{kosm}} \tag{7.33}$$

where: $P_{šum\ uk}$ = total noise;

$P_{šum.vred.}$ = intrinsic installation noise;

$P_{š.kosm.}$ = cosmic noise.

The principal sources of cosmic noise are the Sun, the Moon, and some "radio"-stars. This noise is usually frequencywise widely banded with random polarization. The power of the cosmic noise received by the antenna is

$$P_{š.kosm.} = \frac{P_z \cdot A}{2} = K \cdot T_k \qquad (7.34)$$

where: P_z = radiation intensity in $[W \cdot m^{-2} \cdot H_z^{-1}]$,

A = effective surface of antenna receiver $[m^2]$,

T_k = temperature of the noise of cosmic source read at the antenna.

The relationship between the effective surface of the antenna and its amplification is

$$A = \frac{\lambda^2 \cdot G}{4 \cdot \pi} \qquad (7.35)$$

where G = antenna amplification, and λ = radar wavelength.

If we substitute A in equation (7.34) by (7.35), we obtain

$$P_{š.kosm} = \frac{P_z \cdot \lambda^2 \cdot G}{8 \cdot \pi} \qquad (7.36)$$

Equation 7.36 is good for point radiation source as well as for an atmosphere in which there are no losses. In view of the fact that such an approach is not accurate, correction factors must be introduced. The corrected equation has the form

$$P_{š.kosm.} = \frac{P_z \cdot {}^2\lambda \cdot G}{8 \cdot \pi \cdot K_1} \qquad (7.37)$$

where K_1 = correction due to atmospheric attenuation.

The rough approximation for this factor is

$$K_1 = 10^{(0{,}0004/\sin\varepsilon)} \quad \text{za } \varepsilon \geq 5^\circ \tag{7.38}$$

where ε = elevation angle of receiver antenna.

The expression (7.37) is valid for clear sky, sea level, and frequency range 4-6 GHz.

If the cosmic radiation intensity is known for one frequency, then it can be determined also for any other frequency using the spectral index.

$$\log \frac{P_{s1}}{P_{s2}} = \text{spectral index} = \log \frac{f_1}{f_2}$$

(where P_{s1}, P_{s2} is radiation intensity at frequency f_1, f_2).

The Sun is the strongest cosmic source of electromagnetic radiation with a broad frequency spectrum. The radiation level depends on the phases of its activity. These phases are cyclic, with the recurrence period every 11 years. Figure 7.19 shows the frequency spectrum for electromagnetic radiation of the Sun. From this figure it can be seen that the Sun is

//copy figure//

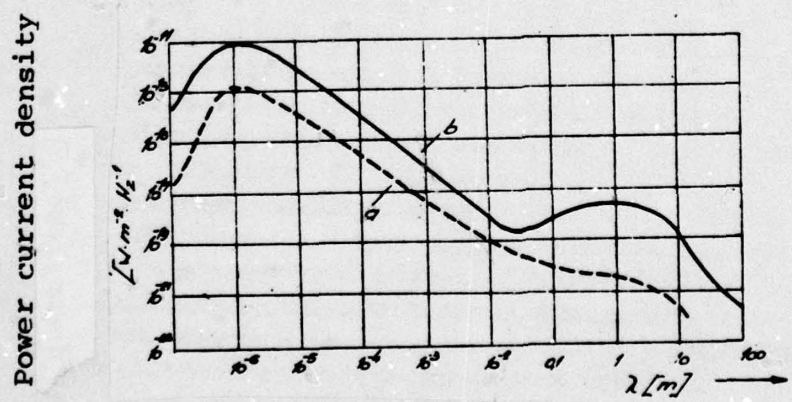


Fig. 7.19. Frequency spectrum for electromagnetic radiation of the Sun: a - calm sun, b - active sun

really a powerful broad-band noise generator.

As a result of individual eruptions on the Sun, increased radiation occurs in the range of radio and radar wavelengths. The duration times of radiation at individual wavelengths are not the same. As a rule, they are longer at lower wavelengths (see Fig. 7.20).

The intensity of Sun's radiation for various wavelengths is given in Table 7.2.

Wavelength [λ]		8 mm	3 cm	10 cm	25 cm	50 cm	1,5 m	3 m	10 m
strength of Sun's radiation P_s	maximum activity	200	32	13	7	.5	0,85	0,23	0,035
$\left[10^{-21} \cdot \frac{W}{m^2 \cdot H_z}\right]$	minimum activity	200	27	6,5	3,5	2,5	0,85	0,23	0,035

Table 7.2.

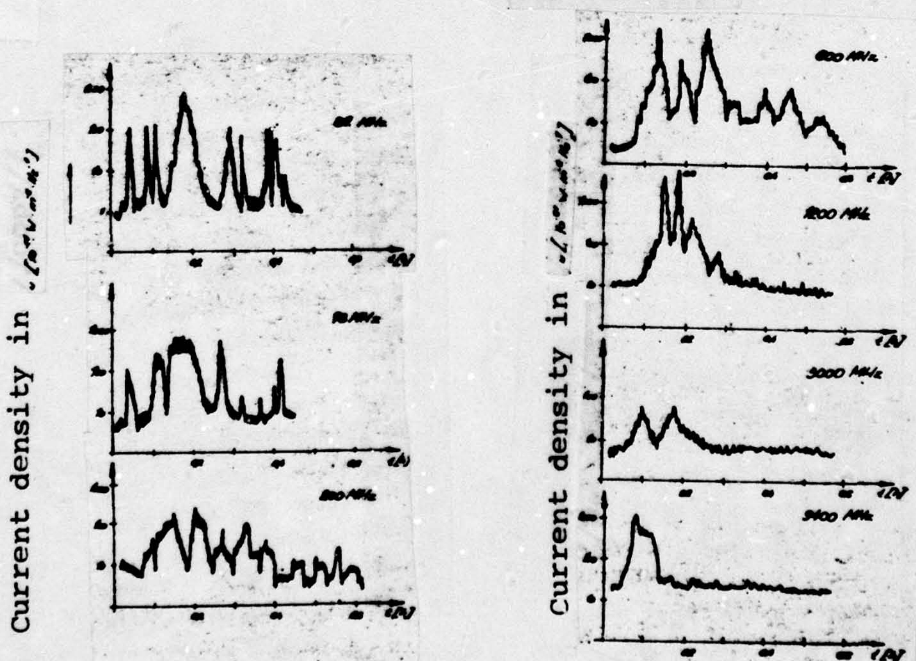


Fig. 7.20. Intensity and duration of radiation dependent on wavelength of a single Sun's radio-flash.

Fig. 7.20. Intensity and duration of radiation dependent on wavelength of a single Sun's radio-flash.

Radiation from the Sun can seriously endanger the operation of those installations which have a higher receiver and antenna sensitivity with high amplification. Here the interfering signal is received by all side fans. The result is the following: Partial or total darkening of radar screens. The duration of this darkening depends on the duration of the activity on the Sun (from several minutes to several hours). The indication on radar indicator is entirely the same as in case of directed broad-band active interference. In Fig. 7.21a,b is shown "Sun interference" pattern under daily operational conditions. In view of the fact that long-range search radars are the most sensitive in the elevation ranges from 0 to 2°, "Sun interferences" occur here at sunrise and at sunset. For radars

a

b

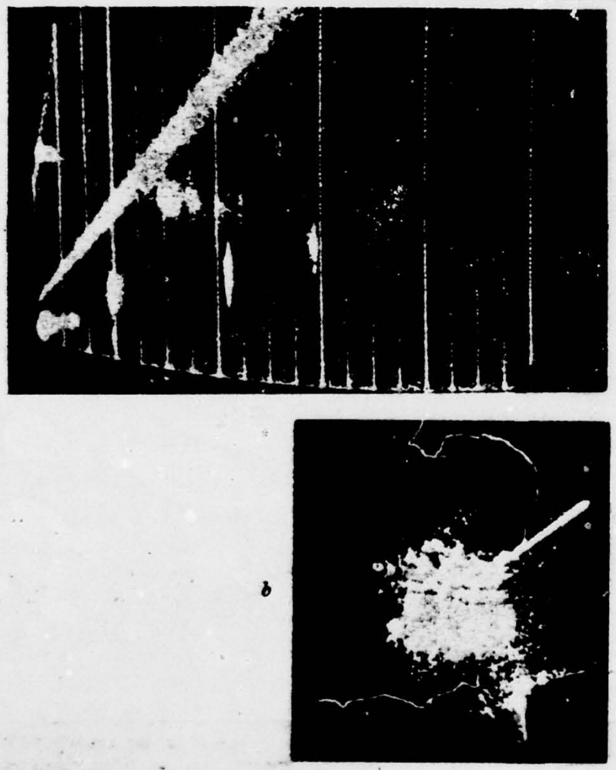


Fig. 7.21. Interference due to sun's radiation as shown on radar: a - radar used for altitude measurement; λ =10 cm, antenna amplifier = 41 db, receiver noise coefficient = 9 = 9 db; b - search radar; λ = 24 cm, antenna amplifier = = 40 db, receiver noise coefficient = 8 db.

used for altitude measurement, this interference lasts until the Sun is no longer present in the elevation search angle.

<u>Other sources</u>. - Radio astronomical observations have shown several thousand individual sources of electromagnetic radiation in our galaxy. However, the majority of them is of a low strength or are at such a position that they do not become expressed as an interference source

Strength current density

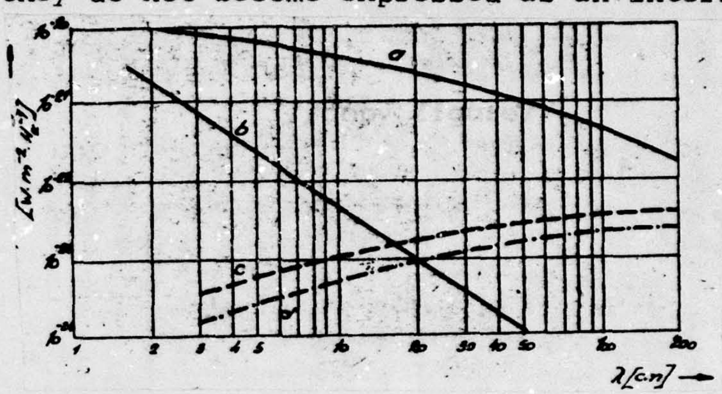


Fig. 7.22. Electromagnetic radiation spectrum of important sources in the cosmos relative to the Sun: a - Sun, b - Moon, c - Cassiopeia, d - Cygnus A

for the reception by the antennas of conventional radar installations. As radiation sources are expressed only Cassiopeia A, Cygnus A, Taurus A, Orion A, and the Moon. Their radiation intensity is given in Fig. 7.22 and in Table 7.3.

Star	Frequency (MHz)	Radiation Intensity $(W\cdot m^{-2}\cdot H_z^{-1}\cdot 10^{-24})$	Probable Error in Intensity Determination (%)	Spectral Index
Gassiopeia *A*	4[illegible]80	10,47	2	−0,76
Taurus *A*	3950	7,169	3	−0,26
Cygnus *A*	4161	4,651	3	−1,19
Orion *A*	4080	4,45	3	−

Table 7.3.

The radiation intensity of Cassiopeia A decreases yearly by 1.1%. Two polarizations are equally represented in its radiation. In case of Taurus A, the radiation is time-independent. The source is of an elliptical shape having widths of 0.070° and 0.043° along the diameters.

Cosmic sources can be used as extraordinary noise generators for the measurement and verification of the antenna radiation diagrams. From the relationships (7.34, 7.36, and 7.37) we obtain antenna amplification:

$$G = \frac{8 \cdot \pi \cdot K \cdot T_k}{P_z \cdot \lambda^2} \quad \text{or} \quad G = \frac{8 \cdot \pi \cdot K \cdot T_k}{P_z \cdot \lambda^2} \cdot K_1 \tag{7.39}$$

By measuring the primary cosmic noise and by precision measurement of the elevation or the azimuthal angle by optical methods (theodolites) one can relatively simply obtain the antenna radiation diagram.

7.1.6. EFFECT OF ROCKET AND JET ENGINE JETS

The jet of jet engine and particularly rocket engines has a twofold effect on the propagation of electromagnetic waves:

- it increases attenuation of the atmosphere with specific modulation;
- it increases the intrinsic radar reflex surface.

The former effect is more pronounced in case of radio-communications systems for guiding rocket projectiles since the line for the radio guidance of the projectile generally passes through the jet of the exhaust gases of the rocket engine.

The mechanism of these phenomena is as a matter-of-fact not yet entirely clear. Tests have shown that hot exhaust gases contain combustion products which increase the number of electrons and ions in the jet. Depending on the type of fuel used, this number is either greater or smaller. Small traces of alkalis in the fuel can also significantly increase ionic concenration.

Tests have shown that engines with liquid fuel experience attenuation of 0.033 db/m at 200 MHz and 0.25 db/m at 9500 MHz. For powder rocket engine it was found that the attenuation is 0.6 db/cm at 9500 MHz. In view of the fact that combustion is nonuniform, the attenuation is also varying with time. Figure 7.23 shows the time dependence of the average attenuation of a small rocket engine using liquid fuel. The attenuation fluctuates with time. At the end of engine operation, the attenuation markedly increases, due to greater elimination of combustion residues.

As can be seen from this example, the attenuation effects are significant and they seriously endanger radio communications passing through the jet. Oscillations in attenuation introduce an additional difficulty in the form of modulations in the systems.

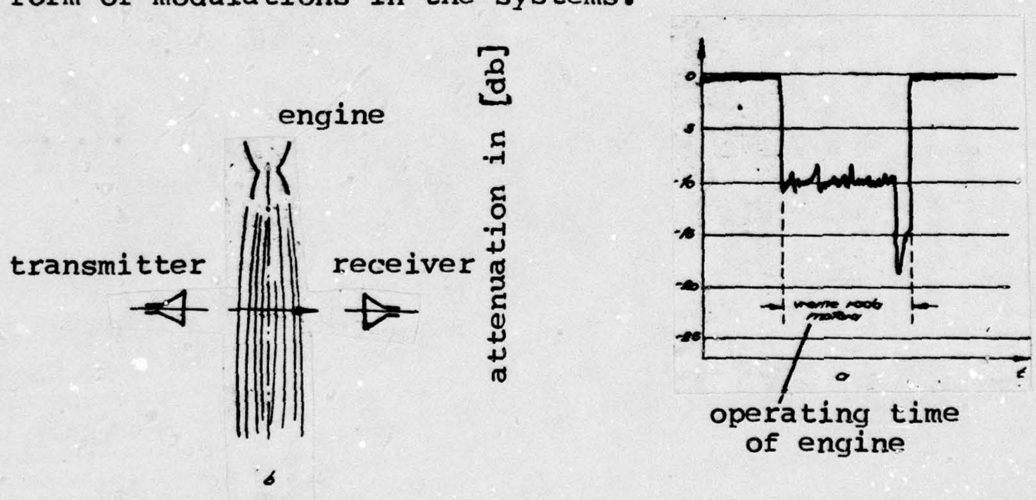


Fig. 7.23. a - attenuation of exhaust jet of rocket engine having pressure of 1200 kp per $\lambda = 3$ cm, b - measurement technique.

The other effect, namely increasing radar reflex surface by introducing nonuniformities in the atmosphere (point 7.1.4. of original p. 176)

, facilitates easier radar detection of the rocket since the surface reflex surface of the target is not only the

body of the rocket but also its jet. This phenomenon is made use of for early detection, especially of intercontinental missiles.

In order to eliminate both phenomena, tests are being conducted with various additions to the fuel which would decrease the electron and the ion content in the jet.

VIII INTENTIONAL RADAR COUNTERMEASURES

Intentional or organized radar countermeasures, be they discrete or course, affect essentially all the performances of the radar installation (individually or in a complex way) as well as the accuracy and reliability of data presentation. Intentional countermeasures are divided into active and passive ones, depending on their genesis.

Active radar countermeasures are created by various kinds of transmitters, with various kinds of modulations and forms of the signal, at the wavelength of the wave region of the radar installation counter which they are employed.

Passive radar countermeasures are created by the effects of increasing or decreasing the reflection of the radar transmitting signal from manmade or natural objects on the terrain or in the space. They make appear a situation on the screen of the radar installation against which the measures are undertaken such as do not correspond to the real situation.

Changing the reflex surface is a countermeasure by which the radar reflex surface is decreased or increased for the object of radar search, as a result that the object being observed indeed acquires different dimensions. This countermeasure is essentially of passive nature, but is because of its special tactical applications in the systematization discussed separately.

Intentional radar countermeasures can, with respect to the applied technical principles, systematically be shown as in Fig. 8.1.

Countermeasures at the narrow frequency region - narrow-band countermeasures - specify thorough knowledge of the frequency of the

interfered with installation, since the frequencies of the jammer and the jammed have to be matched. These are technically simple and cheap installations. If the radar has several channels or if it changes its frequency, their effectiveness is considerably reduced.

Countermeasures at the broad frequency region - broad-band countermeasures - radiate energy within a broad frequency range and thereby interfere with the operation of those installations which are within this frequency region. Because of this they do not cause accurate knowledge of the radar frequency. Their shortcoming is this: High emitted energy within a broad frequency range and hence also their high weight and price.

Countermeasures with erasing by frequency are a compromise between the broad-band and the narrow-band countermeasures. In this way the frequency of the transmitter inside a frequency region is changed by higher or smaller speed. This makes it possible to reach sufficiently high interference effect by erasing in a very short time and on all radars within the range considered.

Countermeasures by the answering method are attained by the reception of the transmitted radar signal, its amplification, and re-emission in such a form and for such a time that echoes appear on the interfered with radar installation such as do not exist in the searched space.

From the systemization of the intentional countermeasures (Fig. 8.1) it can be seen that there exist many technical ways of producing intentional radar countermeasures which can be employed individually or combined, depending on what kind of effect is desired to be achieved. As a result, many different effects are obtained, ranging all the way from damage simulation to the radar installation to the introduction

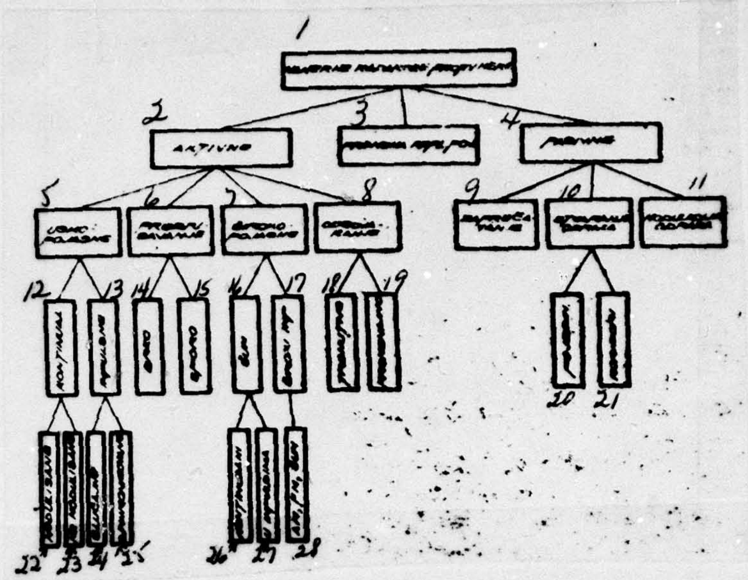


Fig. 8.1. Technical principles of intintional radar countermeasures.
Key: (1) Intentional radar countermeasures; (2) Active; (3) Refl. surf. change; (4) Passive; (5) Narrow band; (6) Erasing; (7) Broad band: (8) Answering; (9) Blocking; (10) Echo creation; (11) Echo modulation; (12) Continual; (13) Pulse; (14) Fast; (15) Gradual; (16) Noise; (17) Wide pulse; (18) Momentary; (19) Variable; (20) Individual; (21) Corridors; (22) Modulated; (23) non-modulated; (24) Random; (25) Synchronized; (26) Continual; (27) In pulses; (28) AM, FM noise.

of new false echoes, and all the way to total prevention of the operation of the installation. For these reasons it is almost impossible to describe all these countermeasures effects at the disposal of the radar user under wartime conditions.

8.1 ACTIVE RADAR COUNTERMEASURES

As can be seen from systematization (Fig. 8.1), active interference of radar installations can be done various ways. Only the principal ways of doing this will be expounded upon below.

8.1.1. CONTINUAL NON-MODULATED INTERFERENCE SIGNAL

Continual non-modulated interference signal is one of the simplest interference techniques. The interference transmitter emits the signal at the radar frequency

$$f_{em} = f_{rad} \quad (8.1)$$

If the strength of the interference signal at the reception site - i.e. at the input into the interfered with radar receiver - is sufficiently large, the interference signal brings the receiver into a saturation state.

The mathematical expression for the continual non-modulated interference signal is

$$u_{om} = U_{o,om} \cdot \cos \omega_{om} \cdot t \tag{8.2}$$

where $U_{o,om}$ and ω_{om} are the maximal amplitude and circular frequency of the interference signal.

The receiving radar signal reflected from the target is equal to

$$u = U_0 \cdot \cos [\omega t + \varphi (R)] \tag{8.3}$$

where U_o, ω, and $\varphi(R)$ are the maximal amplitude, circular frequency, and phase angle of the target signal.

The phase angle varies with the distance and can assume all the values from 0 to 2π. Henceforth we shall assume that the target rests and that hence φ = const. In case that the interference signal and the duty signal arrive at the receiver input at the same time, they are added up in the receiver. At the output of the amplifier one obtains:

$$U_{rez} = A_{poj} \cdot \sqrt{U_0^2 + U^2_{o,om} + 2\, U_0\, U_{o,om} \cos [(\omega - \omega_{om}) \cdot t + \varphi]} \tag{8.4}$$

where: A_{poj} = amplification factor of the amplifier

$\omega - \omega_{om} = \omega$ = beat-frequency.

From equation 8.4 it can be concluded that the effect of non-modulated interference depends on its amplitude and the magnitude of out-of-tuneness between the radar and the jammer, which is determined by the beat frequency.

If the magnitude of the interference signal is such that saturation of the receiver is not attained and if the out-of-tuneness between the radar and the transmitter is minimal, that is if the beat duration is very much higher than pulse duration (equation 8.5)

$$\frac{2\pi}{\omega_{izb}} \gg \tau \tag{8.5}$$

then the resulting signal per one pulse can be written in the form

$$U_{rez} = A_{poj} \sqrt{U^2_0 + U^2_{o,om} + 2\,U_0\,U_{o,om} \cdot \cos\varphi} \tag{8.6}$$

Inasmuch as the phase angle of the reflected signal varies from pulse to pulse due to the motion of the object and since it can assume all the values from zero to $2\pi (0 \leqslant \varphi \leqslant 2\pi)$, the amplitude of the resulting signal also varies

$$A_{poj} \sqrt{U^2_0 - U^2_{o,om}} \leqslant U_{rez} \leqslant A_{poj} \sqrt{U^2_0 + U^2_{o,om}} \tag{8.7}$$

In this case the pulse retains its initial form.

Figure 8.2 shows the time-dependent pulse shapes of a combined duty (intelligent) and interference signal which does not lead to saturation. We see that, depending on the phase displacement of the target signal (φ), positive or negative videosignals appear. If the detector with the video-amplifier is is coupled on directly, then the videosignal is the same as under d in Fig. 8.2. Such a signal decreases the noise on the screen (by illuminating it). The target signals, especially the negative ones, will be barely visible on the display with amplitudinal modulation (type A, K, M, etc.), while they will be entirely invisible on the display with intensity modulation (PPI, RHI, B, etc.). By the introduction of a condenser into the circuit between the detector and the video-amplifier, the unidirectional component is eliminated and a signal such as under e in Fig. 8.2 is obtained. From this figure it can be seen that only the positive videosignal will appear on the display, while the negative one will not want to appear. Since the

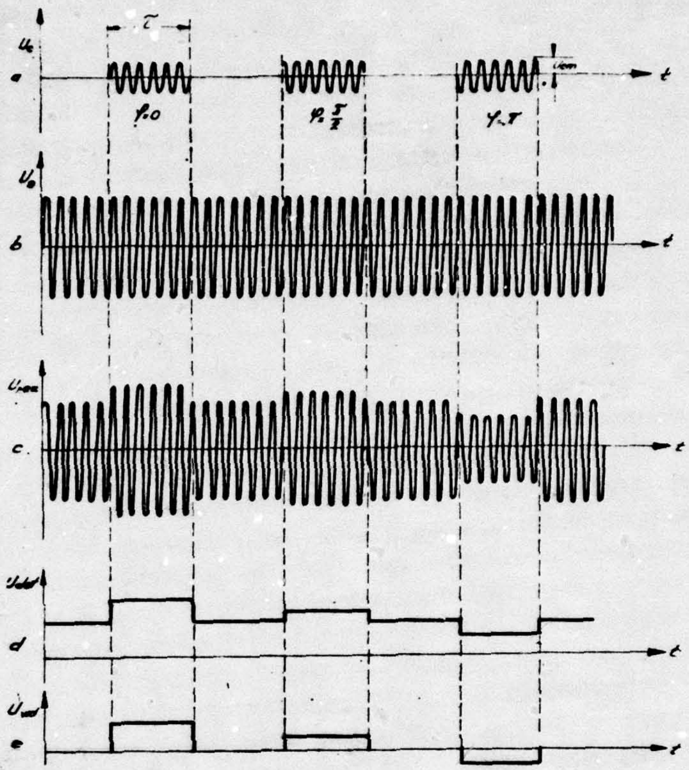


Fig. 8.2. Pulse shapes of the interference signal of smaller amplitude as dependent on time: a - target signal, b - interference signal, c - resulting signal, d - detected resulting signal, e - videosignal.

probability of the manifestation of such a phase displacement through which positive or negative signals are obtained in the result is equal, this type of interference decreases by one-half the number of individual echoes from the target.

Continual non-modulated interference signal of a high amplitude leads the sensitive radar receiver to saturation and target signals become invisible (Fig. 8.3). Because of the saturation, noise appears on the display. The picture on the displays is the same as when malfunction occurs in the receiver (Fig. 8.4).

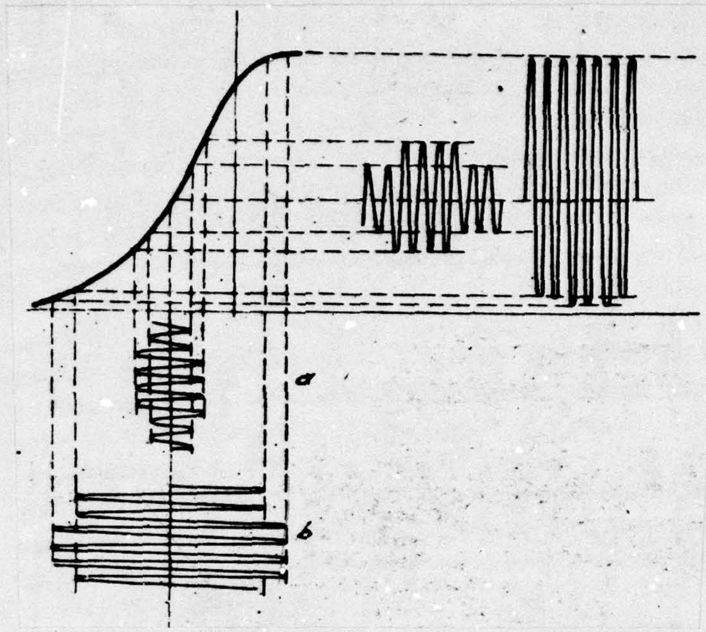


Fig. 8.3. Bringing of receiver to saturation by strong interference signal: a - weak interference signal, b - strong interference signal.

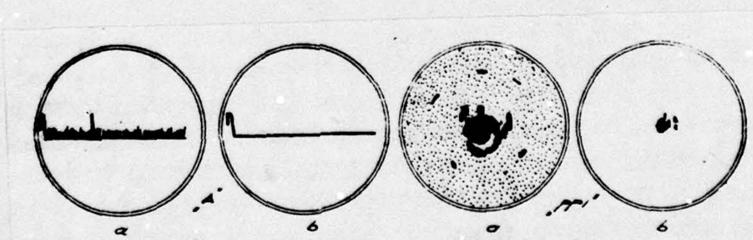


Fig. 8.4. Picture on displays of type A and PPI: a - without interference, b - with interference.

8.1.2. CONTINUAL AMPLITUDE-MODULATED INTERFERENCE SIGNAL

The interference transmitter emits the amplitude-modulated interference signal at the frequency of the jammed radar installation.

If jamming is done by a signal where amplitude modulation is done by a sine signal, then the interference signal appears at the receiver input in the form

$$u_{om} = U_{c,om} \cos \omega_{om} t + U_{c,om} \frac{m}{2} \cos (\omega_{om} + \Omega) t + U_{c,om} \frac{m}{2} \cos (\omega_{om} - \Omega) t \quad \dots \quad (8.8)$$

and the intelligent signal as reflected from target object as

$$u = U_0 \cos [\omega t + \varphi(R)] \quad (8.9)$$

When the level of the interference signal is such that receiver saturation does not result, then the following appear as a result of the interference at the output from the detector:

- unidirectional component as a result of the carrying wave of the interference signal with the same effects as in case of interference by continual non-modulated signal.
- modulated frequency Ω of the interference signal, and
- beat signal between the interference signal and the radar signal.

If video display is protected from propagation of unidirectional component, the modulated component enters and appears on the display in the form of intensity-modulated bright fans (Fig. 8.4). 196

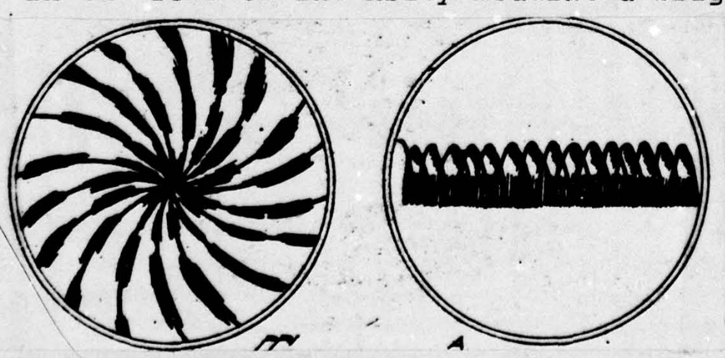


Fig. 8.4. Amplitude-modulated interference on A and PPI indicators.

The density of the fans and their width depend on modulated frequency of the interference signal (higher f_m - denser, lower f_m sparser). If the modulation frequency of the interference signal is a multiple of the pulse frequency of the radar, the fanlike interference rests on the screen. If it is not, the interference travels, i.e. circulates on the screen here and there. The illuminance of the fanlike interference depends on the amplitude of the modulation component (the higher the amplitude, the lighter it is). Consequently, the highest effect of interference will occur when the degree of modulation is high and if the modulation frequency is very much higher than the pulse frequency of the radar.

Besides covering the screen by fanlike interference, this type of jamming also causes:

- disturbances in the saturation of the receiver (in case of a strong signal);
- emergence of bipolar target signals at detector output;
- effect described in point 8.1.1. (original p. 191) //translation p.45/

The amplitude-modulated interference signal is like the sine signal narrow-band in nature and can be employed against all kinds of radars, especially against those which for automatic tracking of the target use conical searching of the space and and even signal zone.

8.1.3. CONTINUAL FREQUENCY-MODULATED INTERFERENCE SIGNAL

Depending on the shape of the signal (sinusoidal, sawlike, etc.) through which frequency modulation of the carrying wave is being effected, various visual effects appear on the indicator. If the sinusoidal shape signal also is of low frequency, the appearance of fans occurs which are more or less illuminated along their width.

8.1.4. CONTINUAL NOISE-MODULATED INTERFERENCE SIGNAL

In every electronic device there is present more or less noise, due to the components used. In case of radar installations, the noise appears together with the intelligent signal from the target in the form of "fine snow" or "grass" on indicators with intensity (such as the PPI type) or amplitude (for instance, type A) modulation, respectively, and thus creates the base (background) of the indicator screen whereupon the target signal appears. In case of radar installations with classical receiver type, the noise level dictates the lower visibility limit of the target signal. It also determines the sensitivity of the radar installation and its range. Therefore, the smallest intelligent signal which will still be seen on the radar is either equal to or greater than the noise level of the installation. This constitution can be written as

$$P_{cilja} \geqslant N_{šuma,radara} \tag{8.10}$$

where: P_{cilja} = the smallest visible target signal

$N_{šuma}$ $radara$ = radar noise level.

The range of the installation in free space amounts to

$$R = \sqrt[4]{\frac{P_i \cdot G^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot N_{šuma,radara}}} \tag{8.11}$$

where: R = radar range,

P_i = pulse strength,

G = antenna amplification,

λ = radar wavelength,

σ = reflex surface of the target,

$N_{šuma,radara}$ = noise level of radar installation.

Besides the intelligent signal of the target, the noise-modulated interference signal also arrives at the input of the radar receiver,

which after detection again appears in the form of noise. The noise as caused by the interference signal and the intrinsic noise add up in the receiver, increase the total noise level, and thereby decrease the sensitivity and the range of the radar by

$$R' = \sqrt[4]{\frac{P_t \cdot G^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \, (N_{\check{s}uma,\ radara} + N_{\check{s}uma,\ omet.}}} \quad \ldots\ldots \tag{8.12}$$

The noise produced in radar installation due to different causing agents is spectrally very similar to white noise which has the same intensity at all frequencies. Because of this, the noise as a modulation frequency of the interference signal must have a somewhat standardized spectral characteristics. Noise diodes, tiratrons in a magnetic field, photomultipliers, and the like, are used as noise generators. Tiratrons in a magnetic field provide noise with a spectral width of approximately 6-7 MHz and with a high amplitude. Photomultipliers give uniform noise to several tenths MHz with amplitude from 10^3 to 10^4 μV/MHz.

The carrying interference signal wave is produced by magnetrons, klystrons, resnatrons, tubes with progressive waves, and similar, with a power from 100 to 1,500 W.

Against radars on the meter and the decimeter wave region, the amplitude modulation by noise is mostly used, whereas frequency modulation by noise is mainly used against radars of centimeter wave region. The effect of either modulation on the screen is the same and leads to increased "snow" or "grass." If the strength of the interference signal is too high, the noise signal brings the receiver into a saturation state. In this case the display of the target signal is not possible.

8.1.5. PULSE INTERFERENCE SIGNAL

Pulse interference is done by a series of high-frequency non-modulated or modulated pulses at the frequency of the jammed radar station. Jamming can be nonsynchronous or synchronous. In case of synchronous jamming the pulse frequency of the interference signal ($f_{imp.om}$) coincides with the pulse frequency of the jammed radar ($f_{imp.rad}$) or is its multiple,

$$f_{imp,om} = n \cdot f_{imp.rad} \quad \ldots . \tag{8.13}$$

where n = 1, 2, 3 ...

In case of synchronous pulse jamming resting bright points appear on radar screen, which are the more similar to the radar echo the more their shape and pulse duration, as well as the power of the receiving interference signal are close to the radar receiving target signal.

Fig. 8.5. Nonsynchronous pulse disturbances: a) several jammers at a large distance, b) one jammer near the radar.

If pulse frequency of the jammer is larger than the pulse frequency of the radar, the number of bright spots on the screen is also larger. Then the separation of the target signal from many interference signals is extremely hampered or made totally impossible.

In case of nonsynchronous pulse interference then there appears a larger or smaller number of bright spots travelling on the screen (Fig. 8.5), independently of the difference in pulse frequencies. The separation of the target signal is made totally impossible.

Pulse jamming of a higher amplitude brings the radar receiver to its saturation state while it lasts. The receiver is insensitive for a certain time and after the pulse (restoration time).

Pulse jamming is one of the extraneous and extremely effective ways of jamming.

8.1.6. JAMMING BY **RESPONDING**

Jamming by **responding** belongs to a group of synchronized pulse interferences, with that difference that for each transmitted radio pulse there is emitted one and sometimes several interference pulses. The effect of this countermeasure is the following: Change in the coordinates or properties of the target, for the purpose of fooling (deceiving) the user or the automatic system, so that it is induced to act on a nonexisting target. Several techniques are employed:

a) The radar-searched target receives the radar pulse and re-emits it it simply or multiply, with a slight delay and the same electrical properties (pulse duration, operating and pulse frequency, phase, and amplitude). The consequence of this is the appearance of one or more false echoes on radar screen which are moved in distance and azimuth from the real echo. The system can be adjusted so that it gives false echoes at the instant of illumination by the main or the side fans of the jammed radar. Figure 8.6 shows the case of using three airplanes equipped with installations for answering in flying over three radar stations. The responders respond on the principal radar fan, and for

each pulse they create two false echoes each. False echoes appear on the radar--airplane line. Each radar in the given case sees 3 true and 6 false echoes.

The disadvantage of this countermeasure is that false echoes can be eliminated by comparison of the received signals from neighboring radar stations. This is so because they appear at various directions and distances.

b) The successive change in target coordinates is a countermeasure which is used against radars which have an in-built automatic device for tracking by coordinates (sight radars of all kinds, radars for guiding and driving, and similar). As also under "a", a signal identical to the true radar echo is created, which first coincides with it in time. The picture on the screen is unchanged. As soon as the user of the jamming installation notices on the shape of the receiving signal that the radar has changed to automatic tracking - which signifies that the procedure against action has begun - he either manually or automatically gradually changes the time position and amplitude of this false echo,

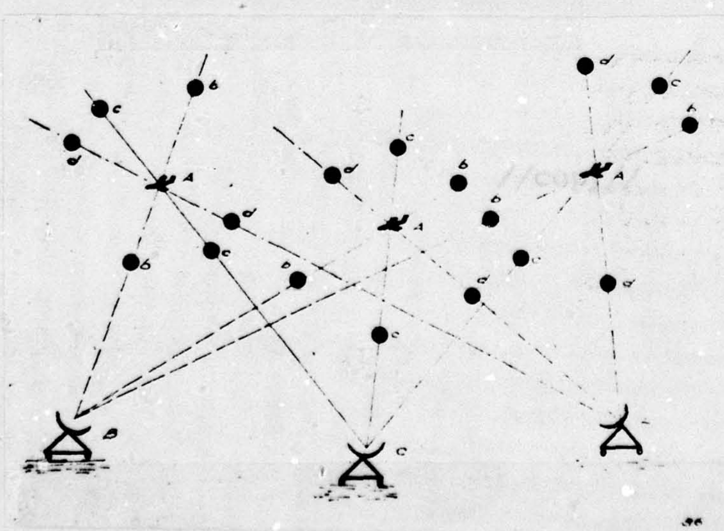


Fig. 8.6. Creation of false echoes by the answering method: A - Airplaes equipped with responders; B,C,D - radars against which the countermeasure is employed; b,c,d - false echoes on radar screens B,C,D.

so that the echo becomes all the larger in amplitude, and in time all the nearer the radar station. Automatic tracking installations "hook on" always on the closer and stronger signal. Unless the user of the radar has been exceptionally careful and unless he noticed the instant of separation of the true target from the false target, the countermeasure will be aimed at empty point and space. When the radar is sufficiently far led from the true target in this way, the jammer can be disconnected.

c) False echo can also be amplitude modulated. In this case, the effect is the same as in case of passive modulation of the radar echo (point 9.2, p. 243 of the original) .

d) Frequency or phase modulation of the false echo can in the case of radars which make use of frequency change (Doppler effect) or phases for the determination of speed and distance of the target create an impression that one has to do with fast or slow, or immovable targets. A similar impression can be obtained by using non-modulated pulse of the responder and cloud with passive dipoles (see point 9.1.3., page 233 of the original) .

With respect to their design, the installations for interference by responding are divided into two main groups, namely:

a) <u>Installations</u> <u>with</u> <u>direct</u> <u>response</u> (transponders), in case of which the received radar signal is amplified to the level for the transmission. Their advantage consists in that during the processing of the signal no changes occur in its essential electrical characteristic (frequency, amplitude, phase, and duration). The response is momentary. For the change in the position of the signal in space the delay between the receiving and the transmitting signal is introduced.

The in-principle schematic of the installation is given in Fig. 8.7. The signal of the radar transmitter is illuminated by the airplane carrier of the jamming installation. At the same time, the receiver antenna of the responder is also illuminated. The receiving signal is amplified in beam A, in beam B it is delayed according to the need, and in beam C it is amplified and emitted through the transmitting antenna. If there is no delay, then the reflected signal and the response signal coincide in time. Delay introduces a known discrepancy between the reflected signal and the response signal. Such a discrepancy is shown on the indicator of the radar as the change of position in space;

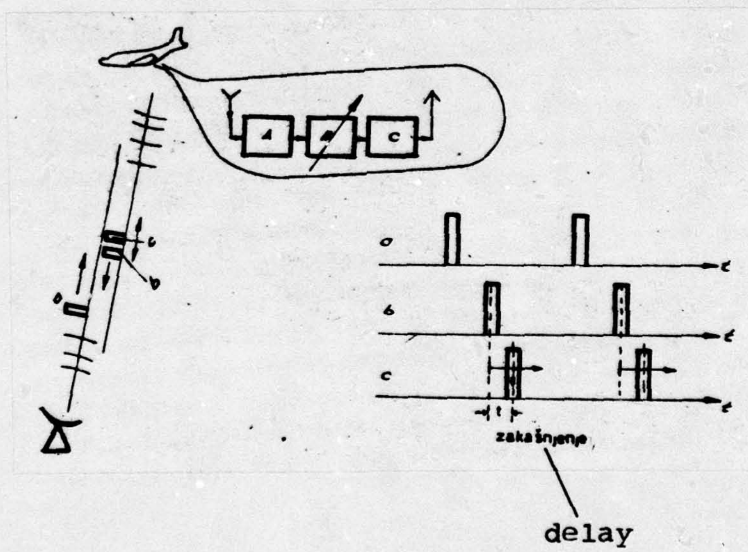


Fig. 8.7. Jamming by direct response: a - transmitted radar signal, b - reflected radar signal from airplane carrier, c - interference signal with variable time, A - amplifier of radar transmitted signal, B - beam of variable delay, C - transmitter.

b) Installations with indirect response (repeaters). Installations of this kind make possible the creation of several false echoes or they

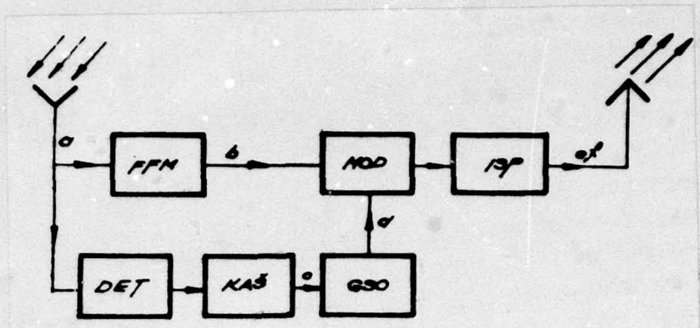


Fig. 8.8. A. Jamming by indirect response. A - block schematic of the installation: FFM - frequency-phase memory of the radar transmitted signal, DET - detector of the transmitted signal, - KAŠ - beam for delaying, GSO - generator of jamming signal, MOD - modulator, IS - output degree of the transmitter;

also introduce a change in electrical characteristics of the signal. The received radar signal is detected, processed, amplified, and re-emitted. This kind of jamming is used for masking the true target, by surrounding it with a greater or lesser number of false echoes. The repetition frequency, the pulse power, the shape and the duration of thusly created interference signals must not be differentiated from the true reflected signal. On the contrary, the enemy can use simple defense means to select and eliminate interference signals.

The in-principle block schematic of a simple installation with indirect response is given in Fig. 8.8.

The radar transmitted pulse in the occasion of illumination of the carrier airplane of the installation also illuminates the receiver

antenna of the jamming installation. The received signal is brought into the beam which "remembers" the frequency and the phase of the transmitted signal (FFM). A part of the receiving signal passes on

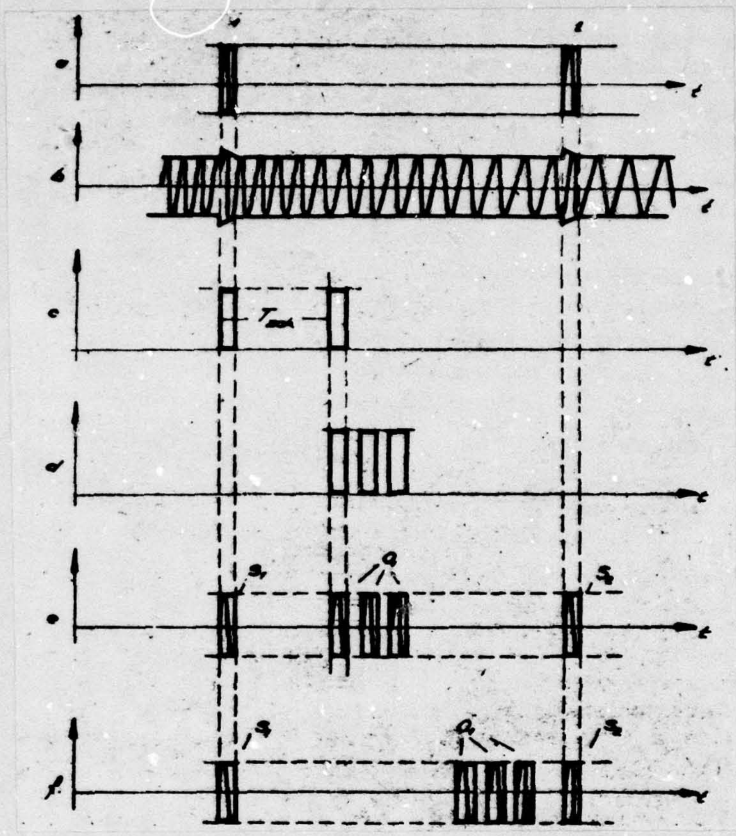


Fig. 8.8. Time shapes of individual signals: B.

a - transmitting radar pulse received by installation antenna, b - frequency- and phase-memoried radar pulse, c - delayed transmitted pulse, delay time T_{delay}, d - generated interference signals, e - transmitted interference signal in moving away, f - transmitted interference signals in approaching.

to the detector (DET), which identifies it. The thusly identified transmitted radar signal becomes reference for time. It is further led through the delaying (KAŠ) beam, which gives the detected signal the delay which is necessary for creating the illusion (T_{delay}). The

thusly delayed signal influences the generator of the jamming signal (GSO), in which for each incoming pulse from the beam, one or more interference pulses are created for the delay, in the form suitable for the operation of the modulator. In the modulator (MOD) occurs the modulation of the "memorized" radar transmitter signal with the interference signal. The modulated signal becomes amplified in the

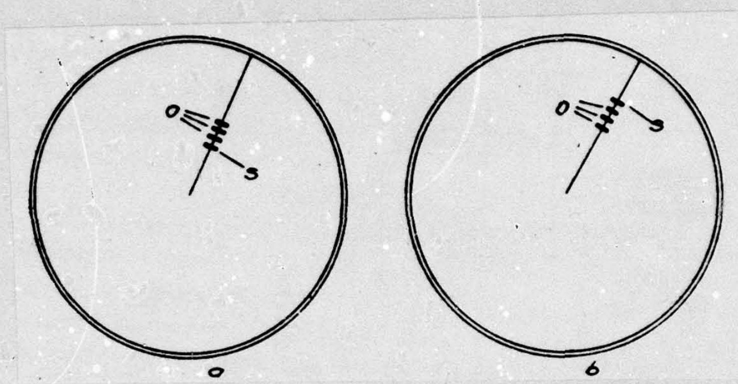


Fig. 8.9. Jamming by indirect response on panoramic indicator (O - interference signals, S - signals reflected from the carrier); a - imitation of moving away targets, b - imitation of approaching targets.

output degree (ISP) of the amplifier and leads to the antenna. On the screen of the radar indicator there appear besides the true reflected signal from the airplane carrier (S_1, S_2) also false signals (O_1, O_2), which, depending on the magnitude of the delay, create the impression of remote and near targets. In Fig. 8.9 is shown the effect of this kind of interference on the panoramic indicator.

8.1.7. BROAD-BAND JAMMING*

In case of this type of jamming, an interference* signal with a

---

Translator's Note: While strictly speaking, "ometanje" translates as "jamming," and "smetnja" translates as "interference", the two terms have been used interchangeably in the translation above, and may so be used in the section below, if a certain term translates better in English than the other.

relatively broad frequency range is created. This range may encompass one or even several regions of radar frequencies (L, S, G, J, X ...) Generally the width of this range is selected such that it covers all frequency possibilities of a single region and there are therefore jammed all the installations which operate in this frequency region (if all other conditions are fulfilled). Their advantage is that they need not be attuned precisely to the radar frequency which they are jamming.

The disadvantage of broad-band jammers is in that they must as a rule have a much larger output power for the creation of the same effect on the radar as achieved by narrow-band jammers. This is so because they must for each width of the permeable scope of radar receiver radiate sufficient jamming power, with the latter in most of the cases being the same as in case of narrow-band jammers. Therefore, the total power of the broad-band jammer must be by as many times larger as the width of the frequency range of the jammer is larger than the width of the permeable scope of the receiver which is to be jammed. The power of the broad-band jammer amounts to

$$P_{\check{s}ir.om} = \frac{\Delta f_{om}}{\Delta f_{prij}} \cdot P_{om} \quad \ldots . \qquad (8.13)$$

where: $P_{\check{s}ir\,om}$ = power of wide-band jammer,

Δ_{fom} = width of frequency scope of the jammer,

Δ_{prij} = width of the permeable scope of radar receiver,

P_{om} = necessary power for jamming of radar.

Such large power values create great difficulties, especially when moving the jammer on the airplane or ship, due to insufficient driving energy and carrying capacity which these media dispose of.

Another disadvantage consists in that even one's own installations can be jammed if according to their geographical position and the frequency region they are within the "range" of the jamming station.

Wide-band jammers are being used to a considerable extent, thanks to the progress of wide-band emission installations. Noise modulation techniques are used for continual or pulse radiation or direct noise amplification (the DINA system - Direct Noise Amplification). Various wide-band amplifiers are used as emission tubes, such as tubes with progressive wave, tubes with opposite wave, carcinotrones, and similar.

Wide-band jammer of sufficient power totally prevents the operation of radars which operate within this frequency range and no effective countermeasures against it exist, with the exception of the transition to the operation with radars operating at an entirely different frequency region. In order that the effect of the jammer be as large as possible, several such jammers are mounted on airplane (vehicle) jammers so as to cover as wide as possible a frequency region. Modern emission technology makes possible the simultaneous emission already at large widths (the entire scopes L, S, G, J, C, X, K), with a tendency to broadening. Another limitation of the scope width are transmitter antennas and their wide-bandedness. But even here has in recent times been achieved a high degree of wide-bandedness using various planar antennas (linear, logarithmic, exponential, and similar).

8.1.8 JAMMING BY ERASING

The method of jamming by erasing of the frequency region is a combination which includes the advantages of narrow-band (low power) and wide-band (high effect) jamming. It is obtained by using a narrow-band jamming

transmitter, whose carrying frequency hastily or falsely traverses the entire frequency region which is to be jammed. The result of this is that all installations which are located within this frequency region become jammed. Effective jamming is possible only the frequencies of the jammer and the radar coincide and if antenna beams are aimed at one another.

Therefore, the rate of erasing by frequency depends on the analysis method by the direction. The complete erasing cycle must be performed within a time period which is smaller or equal to the meeting time of the beams.

$$t_{preb} \leqslant t_{su} \quad \ldots . \qquad (8.14)$$

where: t_{preb} = time necessary for one cycle of erasing

t_{su} = meeting time of the beams.

Figure 8.10 is a comparative diagram for spectra of all kinds of jamming.

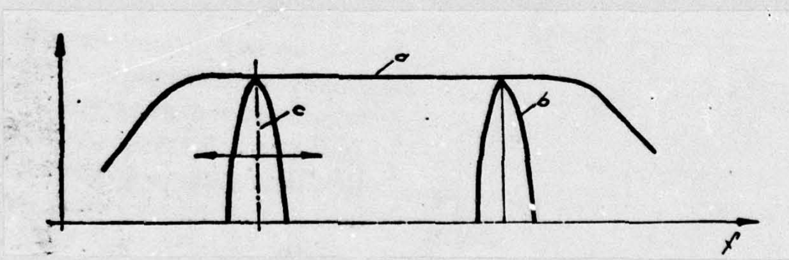


Fig. 8.10. a - wide-band jamming, b - narrow-band jamming, c - jamming by erasing.

Tabular overview of fundamental active radar countermeasures

	a vrsta protivmere	b radna frekvencija ometača	c modulacija ometača	d širina zahvaćenog frekventnog opsega	e efekat na ekranu radaru	f mere odbrane
1.	a kontinualni signal	b radara	c bez	d uska	e nestanak šuma jednolične svetle vremenske baze (npr. za PPI pokazivač-svetle radijalne linije)	f primena sprežnog kondenzatora u videopojačivaču — prijemnici bez zasićenja npr. (IAGC, VARU, MARU), promena frekvencije radara
2.	a modulisani kontinualni signal	b radara	c NF signal, AM ili FM	d uska	e nestanak šuma jednolična, više ili manje osvetljena vremenska baza	f kao pod 1: primena filtra u videodelu za izdvajanje modulacione NF
3.	a modulisani signal šumom, uskopojasni	b radara	c AM, šuma	d šira od propusnog opsega ometanog radara	e potpuno ili delimično pokrivanje ekrana „snagom"; simuliranje kvara prijemnika	f promena frekvencije radara; povećanje prednje snage za povećanje odnosa signal/šum: uzak antenski snop bez bočnih lepeza
4.	a modulisani signal šumom, širokopojasni	b široko područje	c „beli šum"	d široka	e kao pod 3.	f kao pod 3. prelazak na rad sa radarima na drugom frekventnom području
5.	a prebrisavanje	b široko područje	c šum, AM ili FM	d široka u celini, jedinačni signal širi od propusnog opsega radara	e kao pod 1, 2, 3 i 4.	f kao pod 1, 2, 3. frekventni diverziti spoj
6.	a odgovaranje	b radara	c impulsna	d kao radar	e lažne informacije o položaju cilja, simulacija nepostojećih objekata	f programirana impulsna frekvencija radara programirano pretraživanje prostora, promena frekvencije radara aktiviranje odgovarača drugim predajnikom
7.	a odgovaranje, sa sukcesivnom promenom koordinata cilja	b radara	c impulsna	d kao radar	e na početku nema promene kasnije je lažni odraz jači od stvarnog	f kao pod 6 ferkventni diverziti spoj
8.	a bespilotni avion ili projektil opremljen odgovaračem ili pasivnim reflektorima	b radara	c impulsna	d kao radar	e stvaranje lažnih ciljeva	f identifikacija, merama kao pod 6. uništavanje PA sredstvima

Key on following page.

Key: (a) Countermeasure type; (b) Operating jammer frequency; (c) Jammer modulation; (d) Width of frequency scope covered; (e) Effect on radar screen; (f) Defense measures.

1. a - continual signal; b - radar's; c - none; d 0 narrow; e - disappearance of noise of monotonous light time base e.g. for PPI indicator - of bright radial line).

2. a - modulated continual signal; b - radar's; c - NF signal AM or FM; d - narrow; e - disappearance of noise monotonous, more or less illuminated time base; f - as under 1: use of filter in videopart of separation of NF modulation;

3. a - noise modulated signal, narrow-banded; b - radar's; c - AM of noise; d - wider than permeable scope of jammed radar; e - total or partial covering of the screen by "power"; receiver malfunction simulation; f - changing radar frequency; increasing front power to increase signal/noise ratio: narrow antenna beam without side fans.

4. a - noise modulated signal, wide-banded; b - wide region; c - "white noise"; d - wide; e - as under 3; f - as under 3. transition to operation with radars operating at different frequency region.

5. a - erasing; b - wide region; c - noise, AM or FM; d - wide in entirety, only signal wider than permeable radar scope; e - as under 1, 2, 3 and 4; f - as under 1, 2, 3, frequency diverse connection.

6. a - responding; b - radar's, c - pulse; d - like radar; e - false information on target position, simulation of nonexisting objects; f - programmed pulse frequency of radar programmed searching of space, change in radar frequency, activation of responder by another receiver.

7. a - responding, with successive change in target coordinate; b - radar's; c - pulse; d - like radar; e - at start no change later false echo is stronger than true echo; f - as under 6 frequency diverse connection.

8. a - pilotless airplane or missile equipped with responder or passive reflectors; b - radar's; c - pulse; d - like radar; e - creation of false targets; f - identification by measures like under 6, annihilation by PA equipment

The effects achieved by jamming by erasing on radar screens do not differ from the effects of narrow-band jamming, with the exception of this one difference that it appears and disappears independently of the erasing speed of the jammer.

The effectiveness of jamming depends on the meeting time of the beams and will be the greater the longer is the meeting time. The effectiveness can be expressed in the form

$$\eta = \frac{t_{su} + t_{per}}{t_{om}} \quad \ldots \quad (8.15)$$

where: η = effectiveness, t_{om} = duration of jamming, t_{su} = duration of meeting in the jamming time, t_{per} = persistence time of the indicator screen of the jammed radar.

8.2. TACTICAL APPLICATION OF INSTALLATION FOR ACTIVE JAMMING

Basically there are two ways of application of the installation for active jamming:

- direct and indirect protection of target object.

8.2.1. DIRECT PROTECTION OF TARGET OBJECT

In case of direct protection of the target object the installation for active jamming is located at the target proper. Under target is understood a flying, floating, or ground object. Figure 8.11 shows the case of a flying and floating object.

Jamming installation creates a spherical field of the jamming signal around protected object. Due to the spherical jammer field, radar installation cannot determine the accurate coordinates of target object. Action which follows radar detection or driving becomes more and more

inaccurate with decreasing distance (due to increased power ratio).

Such a technique is used for the following:

- protection of flying objects from radar-guided missiles or airplanes;
- protection of ships from radar-equipped airplanes or missiles, and
- protection of cities, factories, and other vital objects from reconnaissance and bombardment with the help of radar installations.

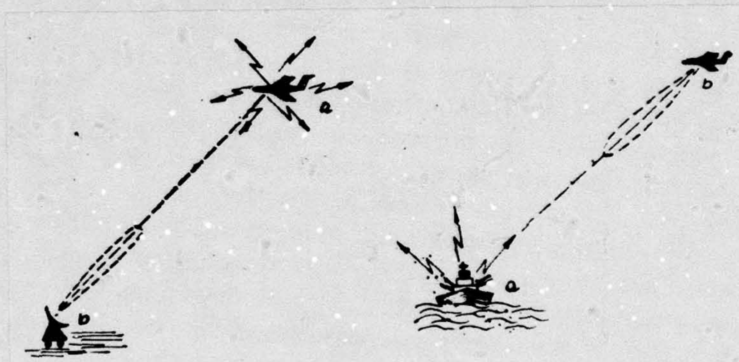


Fig. 8.11. Direct protection of target object by active jammer: a - active jammer on the airplane or ship which it protects, b - ground or airborne radar.

Jamming power necessary for direct protection is smaller than that of jammer for indirect protection, due to the fact that the distance between the radar and the jammer is smaller. Their method of calculation is given in point 8.3 (p. 213 of original article)

8.2.2. INDIRECT PROTECTION OF TARGET OBJECT

In this case the installations for active jamming are situated on the object which may be at a distance from the protected object. For the

case of flying objects this can be one of formation airplanes, such as the airplane for electronic support (Fig. 8.12).

This method is used also in case of floating objects.

It is more expedient for jammer power ratios if the airplane or the ship with electronic support is present directly with the formation which it protects. Then the indirect protection method changes into direct protection. Insofar as this is not the case, one must for each individual case specially consider the width of radar beam ($\Delta\beta$), the angle under which the jammer is located relative to radar beam axis ($\Delta\beta_{om}$) and reciprocal radar--target (R_{cel}) and radar--jammer ($R_{omet.}$) distances (designations from Fig. 8.12).

Then on the basis of these considerations one can determine the power needed for effective protection by active jammer. This is so because

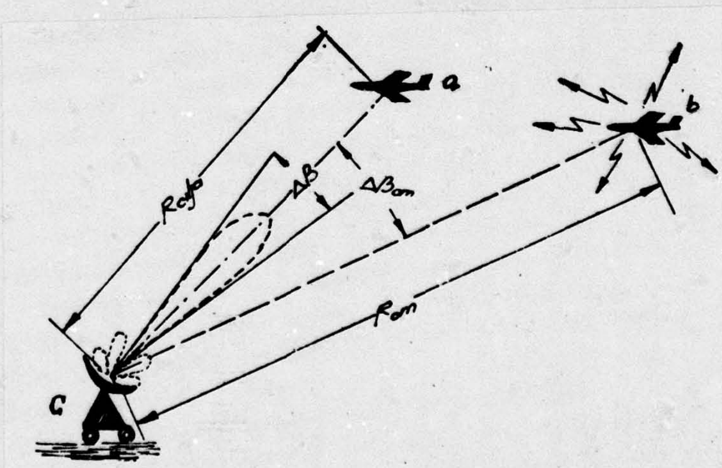


Fig. 8.12. Indirect protection of target object by active jammer: a - airplane target; b - airplane carrying electronic support; c - ground radar.

radar receives the target signal by the maximum of the main fan of the radiation diagram, whereas the jamming signal is received by a

part of the main fan, where amplification is smaller, or even by the side fan.

The procedure of calculation the distance and the necessary powers of the jammer is given in point 8.3 (p. 213 of original copy) below.

Sometimes the installations for active jamming are situated on carriers which the target sends ahead in front of itself in the direction of its motion or in the direction of the radar installation. This can be missiles or pilotless airplanes dispatched in front of airplane formation or ships (Fig. 8.13). (See also Chapter XII, p. 310 of copy).

It is customary that the carrier of the installation for jamming is launched and guided by radio from the target plane. The power and distance balance in this case are in favor of the installation for jamming. In case of application one has to make sure that the angle $(\Delta\beta_{om})$ between the direction of the axis of the radar beam to the target and the direction radar--carrier of the jammer will be as small as possible. The calculation procedure is the same and identical to the preceding case and is given in the following chapter.

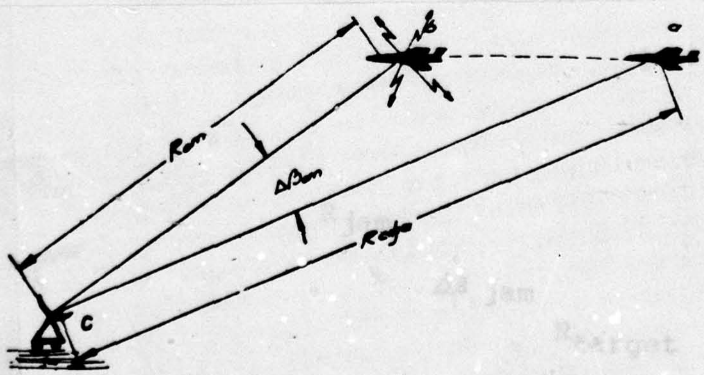


Fig. 8.13. Indirect protection by jammer as precursor: a - target, b - carrier of installation for active jamming, c - radar.

8.3. NECESSARY POWER AND RANGE OF ACTIVE JAMMER

If effective active jamming is desired, the power of the jamming signal at the input into the classical radar receiver must be at least so large that it effectively exceeds the simultaneously incoming reflected signal from the target. This means that the power of the jamming signal at the reception site must be at least the same as the minimal receiving signal or is increased by a certain security factor which is generally also called the jamming coefficient. Since in classical radar receivers the minimal receiver signal depends on the noise level of the receiver (equation 8.10, p. 197 of copy)//p. 52 of translation//, the minimal jamming signal at the jammin site shall be:

$$P_{pr.om} \geqslant \gamma \, P_{prij.cilja} = \gamma \cdot N_{šuma\ radara} \quad . \ . \ . \ . \qquad (8.16)$$

where: γ = jamming coefficient $(1 \leqslant \gamma \leqslant h)$;

$P_{prij.\,cilja}$ = minimal receiving signal,

$N_{šuma\ radara}$ = noise level of radar receiver,

$P_{pr.\,om}$ = jamming signal at reception site.

On the basis of the radar equation for propagation in free space, the receiving signal reflected from the observed signal in air is:

$$P_{prij.cilja} = \frac{P_t \cdot G^2_{rad} \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot R^4} \quad . \ . \ . \ . \qquad (8.17)$$

where: P_t = pulse power of the radar in [W]

G_{rad} = radar antenna amplification

λ = radar wavelength in [m]

σ = target reflex surface in [m^2]

R = radar--target distance in [m]

All the signals shall be displayed on the radar screen which are larger than the radar noise level, which means all those for which the relation holds true

$$P_{pri,} \geqslant N_{šuma\ radara}$$

The majority of jamming signals received by the jammed radar receiver are obtained from the equation for unidirectional transfer. In case of propagation in free space the majority of the receiving jamming signals are

$$P_{pr.om} = \frac{P_{om} \cdot \Delta f \cdot G_{om} \cdot G_{rad} \cdot \lambda^2}{(4\pi \cdot R)^2} \dots \tag{8.18}$$

where: P_{om} = transmitting power of the jammer used by permeable scope of the radar in [W],

G_{om} = amplification of jammer antenna,

λ = jammer wavelength in [m],

Δf = width of permeable scope of radar in $[H_z]$,

R = radar--jammer distance in [m].

If the equation for the receiving signal reflected from radar target 8.17 is compared with equation for the receiving jamming signal 8.18, it can be seen that:

- the power of the receiving signal from the target increases with decreased distance with the fourth power of the distance $\left(\frac{1}{R^4}\right)$;

- the power of the jamming receiving signal decreases with the second power of the distance $\left(\frac{1}{R^2}\right)$,and that because of this

- with increased distance the required power for effective jamming decreases.

If the jammer is situated at the target proper (point 8.2.1. on p. 210 of copy)//p. 67 of translation//. then at a certain distance from the radar both signals are equal. If from this distance the target still approaches, the receiving signal from the target shall be stronger than the jamming signal and jamming becomes ineffective. This distance is called <u>self-protective distance of the radar</u> (R_{sz}) and it is obtained

by equating equations (8.17) and (8.18).

$$P_{prij.cilja} = P_{pr.om} \quad \ldots \tag{8.19}$$

$$\frac{P_i \cdot G^2_{rad} \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 R^4} = \frac{P_{om} \cdot \Delta f \cdot G_{om} \cdot G_{rad} \cdot \lambda^2}{(4\pi R)^2}$$

The self-protective distance is

$$R_{sz} = \sqrt{\frac{P_i \cdot G_{rad} \cdot \sigma}{4 \cdot \pi \cdot P_{om} \cdot \Delta f \cdot G_{om}}} \quad \ldots \tag{8.20}$$

From equation 8.20 it can be seen that the self-protective zone for the radar shall be the larger the larger is its output power and that the orientation of the antenna beam shall be the smaller the larger is the power of the jammer.

If for a certain given radar, jammer, and target the equations 8.17 and 8.18 are calculated out, the power diagram relative to the distance can be plotted (Fig. 8.14). The intersection of the curve for the receiving signal of the target $(P_{pr \cdot cilja})$ amd ratio of the receiving power of the jamming signal $(P_{pr \cdot om}$ is within an equisignal zone (self-protective distance = R_{sz}). Active jammer is effective in the shadowed region. The more the jamming coefficient (γ) is larger than unity, the more the self-protective distance decreases, and if it is smaller, it increases.

From equations 8.16, 8.17, and 8.18 one can find the necessary power of the active jammer at a distance R which is necessary for covering the target of reflex surface σ.

$$P_{om} = \frac{1}{\gamma} \cdot \frac{P_i \cdot G_{rad} \cdot \sigma}{\Delta f \cdot G_{om} \cdot 4\pi R^2} \quad \ldots \tag{8.21}$$

where: γ = jamming coefficient $(1 \leqslant \gamma \leqslant r)$,

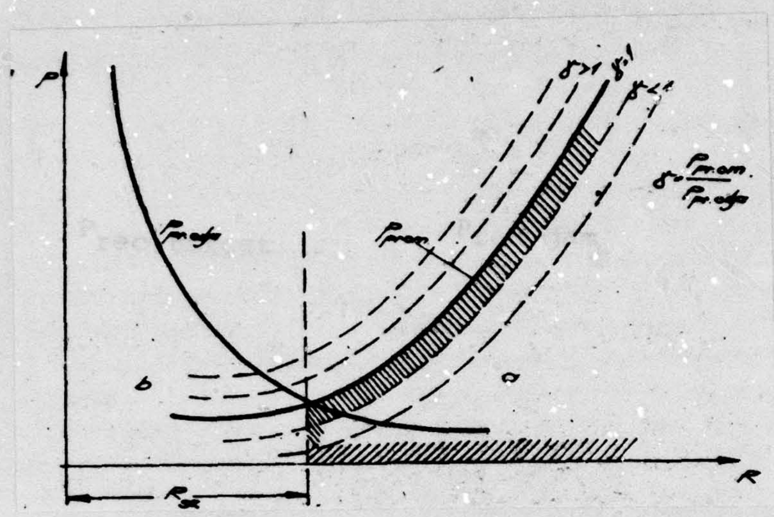
P_i = radar pulse power, [m]

G_{rad} = amplification factor of radar antenna,

σ = target reflex surface, $[m^2]$

R = radar--target distance, $[m]$

Δf = permeable range of radar, $[H_r]$



$$\gamma = \frac{P_{rec\ jam}}{P_{rec\ target}}$$

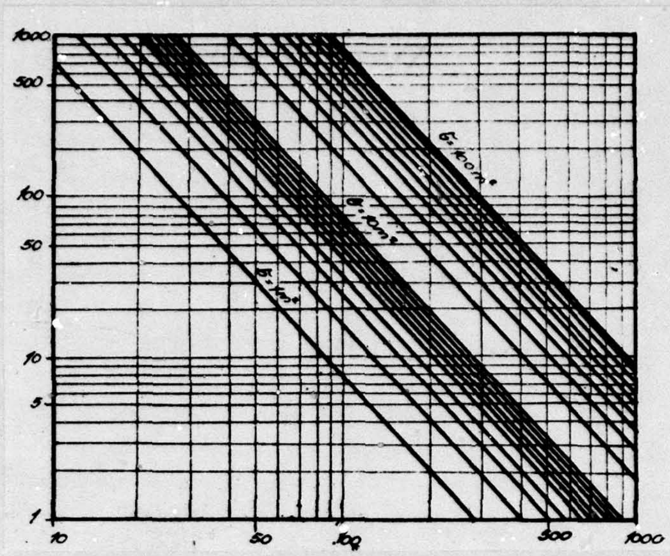
Fig. 8.14. Power diagram relative to the distance; a - effective jammer region, b - noneffective jammer region.

If we assume that the jamming coefficient and the antenna amplification od active jammer are equal to unity, then we can for every radar type using equation 8.21 calculate the minimal required energy which is necessary for the covering up of the target of reflex surface σ. For instance, for radar with data: pulse power Pi = 1MW, wavelength λ = 10 cm, antenna amplification G_{rad} = 30 db, the width of permeable range Δf = 5 MHz, and under the assumption that

$$\gamma = 1$$
$$G_{om} = 1$$

the diagram of the necessary powers of the active jammer as a function of the distance and the reflex surface of the target which is desired to be concealed by jamming is obtained. This diagram is shown in Fig. 8.15. If the active jammer is not situated at the target searched - which means that indirect protection is done by the active jammer

P_{jam} in [mW]



Distance in [km]

Fig. 8.15. Diagram of the required powers of active jammer for the given radar.

(point 8.2.2., p. 211 of copy) // p. 68 of translation// - the required powers and jamming distances are obtained on the basis of the following consideration.

From Figs. 8.12 and 8.13 it can be seen:

- that the distances between the radar and the jammer and the radar and the target are different, and

- that the radar receives the target signal by maximum of the main fan, whereas it receives the jamming signal by some other value, which in every case is smaller than the maximum. This value can be expressed as a function of the deviation of antenna amplification relative to azimuth and elevation from the direction of the main maximum G_{rad}

$G_{rad}(\Delta\beta_{om}, \Delta\varepsilon_{om})$.

The jamming signal at the reception site amounts to

$$P_{pr.om} = \frac{P_{om} \cdot \Delta f \cdot G_{om} \cdot G_{rad}(\Delta\beta_{om}, \Delta\varepsilon_{om}) \cdot \lambda^2}{(4\pi R)^2} \quad \ldots . \tag{8.22}$$

If equations 8.22 and 8.17 are substituted in ratio 8.16, the required power of the jammer is obtained as

$$P_{om} = \frac{1}{\gamma} \cdot \frac{P_t \cdot G^2_{rad} \cdot \sigma}{\Delta f \cdot G_{om} \cdot G_{rad}(\Delta\beta_{om}, \Delta\varepsilon_{om}) \cdot 4\pi} \cdot \frac{R^2_{om}}{R^4_{cilja}} . \tag{8.23}$$

At the specific distance radar--target, the maximum radar--jammer distance for jamming to be effective amounts to:

$$R_{om} = R^2_{cilja} \sqrt{\frac{\gamma \cdot P_{om} \cdot \Delta f \cdot G_{om} \cdot G_{rad}(\Delta\beta_{om}, \Delta\varepsilon_{om}) \cdot 4\pi}{P_t \cdot G^2_{rad} \cdot \sigma}} \tag{8.24}$$

For the target to be effectively concealed by the jammer located at a distance R_{jam} from the radar, the distance target--radar must be at least

$$R_{cilju} = \sqrt[4]{\frac{P_t \cdot G^2_{rad} \cdot \sigma \cdot R^2_{om}}{\gamma \cdot P_{om} \cdot \Delta f \cdot G_{om} \cdot G_{rad}(\Delta\beta_{om} \cdot \Delta\varepsilon_{om}) \cdot 4\pi}} \quad .. \tag{8.24}$$

IX PASSIVE RADAR COUNTERMEASURES

Under passive radar countermeasures we understand:

a) signals which appear at the input to the jammed radar receiver as a result of the reflection of electromagnetic energy from massive objects in space;

b) signals reflected from the searched object in space which in amplitude, phase or time of appearance do not correspond to actual dimensions, properties, and position of target object in space, and

c) effects which cause changed properties of space in which electromagnetic waves propagate.

It is obvious that passive countermeasures under a) and b) are useful only against installations which for their operation use the energy reflected from the object under observation, namely only against radar installations. The countermeasure described under c) is used in all electronics devices whereby the change in the properties of the environment in which electromagnetic waves propagate can affect their operation (radars, directed radio communications, etc.).

Passive radar countermeasures were started to be employed during World War II and quite successfully. Later, active countermeasures predominated, whereas today increased attention is again devoted to passive countermeasures, due to their universality, high effectiveness, simplicity, and economic factors. Passive countermeasures can attain various effects - from the creation of false echoes all the way to the change in magnitude and shape of the reflex surface.

9.1. CREATION OF FALSE ECHOES, ARTIFICIAL OBSTACLES, BARRIERS, OR SCREENS (CURTAINS) ALONG THE PATH OF PROPAGATION OF ELECTROMAGNETIC WAVES

At the beginning, metallic paper bands or aluminum foil strips were employed for the mentioned purpose, whereas nowadays thin wires, metalized plastic fibers, artificial ionized layers, clouds of vaporized metals, small metallized plastic baloons, passive reflectors, and similar, are used. The application of all these means has the same purpose, i.e. the creation of a greater or smaller number of false echoes for the sake of confusing the operator and to make it impossible for him to separate false targets from true targets or the creation of large false echoes in the form of a "corridor" through which the true targets cannot travel undisturbed.

For the creation of passive interference against radar on meter wavelengths, aluminum foil or metallized paper bands are used the most frequently. Metallized plastic or glass fibers are the most economical against radars on centimeter domain.

Passive countermeasures of this kind have been called differently in different countries: "Chaff" in USA, "Window" in Great Britain, "Düppel" in Germany, "passivny otrazhatel'" in the USSR. In the text further below we shall call them "passive dipoles."

9.1.1. CREATION OF FALSE ECHOES BY MEANS OF PASSIVE DIPOLES

Passive dipolse are the most widespread means for the creation of false echoes or for the masking of true targets.

Those passive dipoles which are attuned to the wavelength of the radar station against which they are employed represent in the electrical

sense the semiwave dipole lengths $l = \frac{\lambda}{2}$, which are initiated if they are within the zone of "illumination by radar beam", and thus become intensive secondary sources of electromagnetic energy.

In order to obtain the maximum resonance effect, the length of the passive dipole is always selected as a little shorter than half the wavelength at which it is to be effective. The shortening coefficient k

$$k = \frac{l}{\frac{\lambda}{2}} \approx 0{,}95 \quad \ldots. \qquad (9.1)$$

where: l = length of dipole in [m], and

λ = wavelength of radar in [m].

The corrected length of passive dipole is:

$$l = 0{,}475\,\lambda \quad [m] \qquad (9.2)$$

In practice the bands are cut with small deviation in length (± 5-10%). This deviation slightly decreases their reflection effectiveness, however this shortcoming is made up by their higher frequency wide-bandedness. Such cutting of the bank can be employed also in case of radars whose operating frequencies also differ by ± 10%.

In order to determine the required quantity of the passive dipole sufficient for the concealing of any given object of the specific radar reflex surface, one must first determine the radar reflex surface of an individual dipole.

The radar reflex surface of a single passive dipole randomly oriented in space is given by expression

$$\sigma = 0{,}86 \cdot \lambda^2 \cdot \cos\theta \qquad (9.3)$$

where θ is the angle between the normal on the passive dipole and the direction of the incoming beam, as seen in Fig. 9.1.

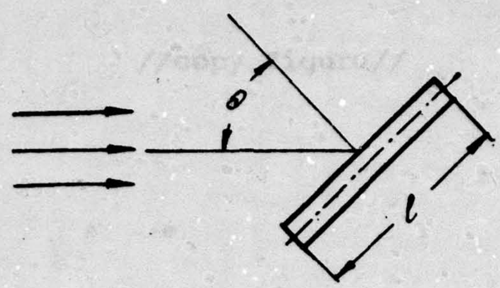


Fig. 9.1. Illumination geometry of passive dipole.

The maximum value is obtained when θ = θ and amounts to

$$\sigma_{max} = 0.86\lambda^2 \tag{9.4}$$

An the angle θ = 90° the value of the reflex surface is σ = 0. Since because of the ejection into the space the dipoles are randomly distributed relative to the direction of illumination, the average value of radar reflex surface of a single dipole σ_0 from a cloud of passive dipoles as obtained on the basis of the theory of probability and practical measurements is as follows:

calculated: $\sigma_0 = 0,17\lambda^2$

empirical: $\sigma_0 \approx (0,11 \div 0,18)\lambda^2$.

In practice one usually uses

$$\sigma_0 = 0,15\lambda^2 \tag{9.6}$$

The total average radar reflex surface of cloud σ_{obl} formed from n passive dipoles is the aggregate of average radar reflex surfaces of individual passive dipoles

$$\sigma_{obl} = \sum_{n=1}^{n} \sigma_0 = n \cdot \sigma_0 \tag{9.7}$$

If it is desired to use the passive dipole cloud to mask or conceal the true target, the average reflex surface of the cloud must be at least

as large as the reflex surface of the concealed target.

$$\sigma_{obl} \geqslant \sigma_{cilja} \tag{9.8}$$

The minimal number of passive dipolse in the cloud occurs when both reflex surfaces are the same. Using relations (9.8, 9.7, and 9.6) we obtain for the minimal number of dipoles in the cloud

$$n_{min} = \frac{\sigma_{cilja}}{\sigma_{obl}} = \frac{\sigma_{cilja}}{0{,}15\lambda^2} \ldots . \tag{9.9}$$

where: n_{min} = minimal number of dipoles [kom]

σ_{cilja} = reflex surface of target which is concealed in [m^2] and

λ = wavelength of radar in [m].

Passive dipoles are thrown out of the airplane by means of special devices, or from ships by means of vertical tubes and compressed air, or through rockets and special artillery grains. In case of all the various methods used, a known number of dipoles become damaged upon ejection due to tearing or bending, which represents a loss in the total reflex surface of the cloud. Another loss are the dipoles which remain glued together in the cloud; they, on the one hand, decrease the total reflex surface of the cloud, and on the other hand, due to the high falling rate "expand" the cloud to a larger space and thereby again decrease the reflex surface of the cloud. Because of these effects, the minimal number of passive dipoles in the cloud is increased by 20-50%.

The definitive form of equation (9.9) for the number of dipoles in the cloud is

$$n = (0{,}12 - 0{,}15)\ \frac{\sigma_{cilja}}{0{,}15\lambda^2}\ [kom] \tag{9.10}$$

where: σ_{cilja} = radar reflex surface which is concealed in [m^2],

λ = radar wavelength against which concealing is done in [m].

The average radar reflex surfaces of some targets are given in Table 9.1.

air target		σ_{cilja} in $[m^2]$	ground target	σ_{cilja} in $[m^2]$
airplanes:	DC-8	130	cruiser	14,000
	DC-4	55	tanker	2,400
	BOEING 707	45	destroyer	160
	Caravelle	35	submarine above water	150
	Metropolitan	16	patrol ship	80
	Canberra	12	patrol boat	1.5
	DC-3	10	submarine periscope	0.4
	J-29	3	man 1.80 m tall	0.8
	F-86	1.5		
	MIG-21	1-1.5		
ballistic missile warhead		0.2		

Table 9.1. Average radar reflex surfaces of known targets expressed in m^2.

Passive dipoles are ejected from the airplane automatically in the required time intervals and in packets which contain the required number of the dipoles. Air currents spread the dipoles over the airspace and the latter form clouds within a very short time, if there are no other currents, and this cloud then slowly falls to the ground. The rate of falling of the dipole made of aluminum foil in calm air is 30-60 m/sec. Tests have shown that the reflex surface changes all the time until the cloud is formed in the final magnitude. This surface the cloud then retains until it reaches the ground. Figure 9.2 shows the measured value of the reflex surface of the cloud formed by aluminum tin foil band 9.2 cm in length as a function of time elapsed since ejection. The bands are ejected from a height of 3000 m. As can also be seen from Fig. 9.2, the cloud reaches its maximal radar reflex surface just

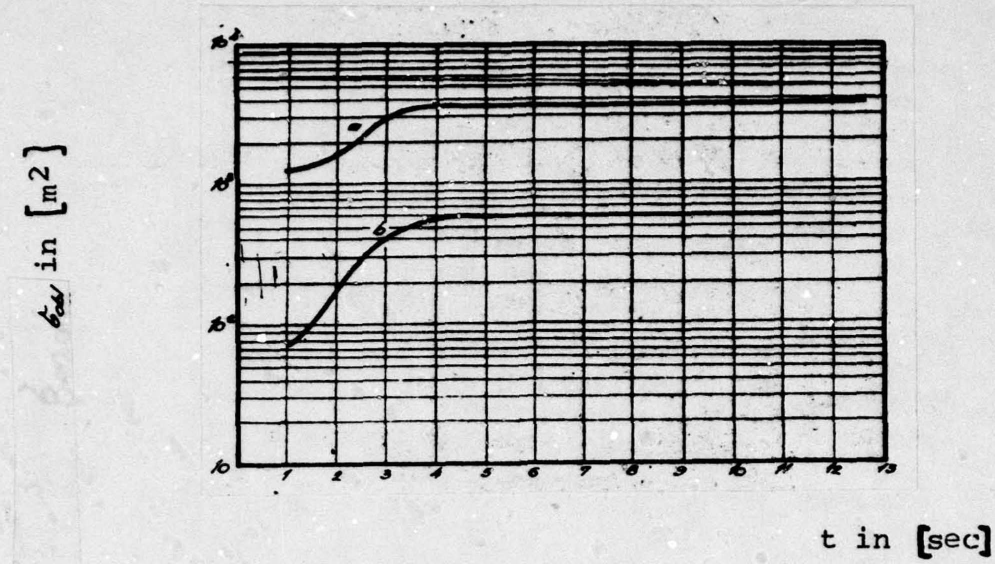


Fig. 9.2. Dependence of radar reflex surface of a passive dipole cloud on time after ejection, a = $3.75 \cdot 10^6$ dipole and horizontal polarization of radar beam, b = $6.25 \cdot 10^5$ dipole and vertical polarization of radar beam, t = time elapsed since ejection instant.

a few seconds after ejection.

Atmospheric turbulence, initial position, aerodynamics of passive dipoles, and wind effect are the reason why all these dipoles inside the cloud do not have the same rate of motion toward earth and in the direction of the illuminated radar. The component of the relative velocity in the direction of the radar causes a doppler frequency change.

$$f' = \frac{c + v_r}{c - v_r} f \tag{9.11}$$

where: f = frequency of illuminated beam,

f' = frequency of reflected beam,

c = velocity of light,

v_r = velocity component in the direction of the radar.

The difference between f' and f is the so-called doppler frequency change and it amounts to

$$f_D = f' - f = \frac{2v_r}{c-v} \cdot f \tag{9.12}$$

Since the velocity of the dipole is small relative to the velocity of light, equation (9.12) can be written in the known form

$$f_D = \frac{2v_r}{c} \cdot f = \frac{2v_r}{\lambda} \tag{9.13}$$

It has been shown experimentally that the velocities of the dipole mainly group around two values - the larger and the smaller value - and this is the result of the different initial position of the dipoles and their different weight (Fig. 9.3).

The total velocity of passive dipoles in the direction of the radar is made up of three components:

- velocity component due to free fall - v_1,
- velocity component due to air turbulence - v_2,
- velocity component due to movement of air mass - v_3.

Inside the passive dipole cloud all these components of motion are represented, and this at different number of the dipoles. As a result of this, a large fluctuation in the frequency of the receicing signal is observed, which varies over the entire falling time. Figure 9.3a

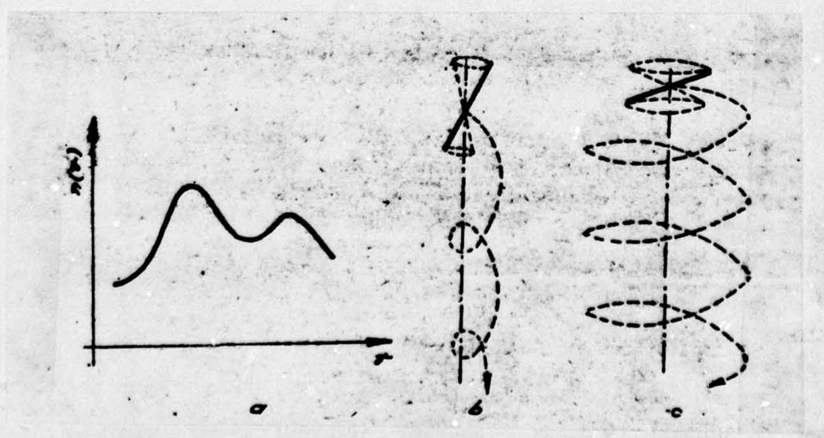
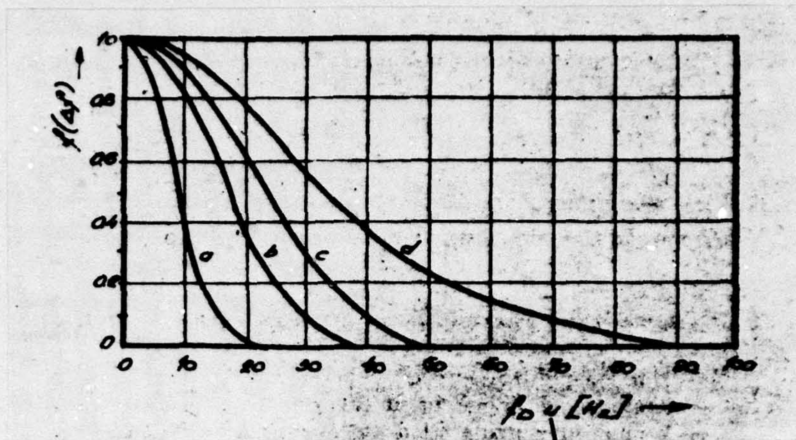


Fig. 9.3. a) distribution of passive dipoles in the cloud with respect to velocity, b) path of "fast" dipoles, c) path of "slow" dipoles.

dipoles.



in

Fig. 9.3a. Amplitudinal dependence of frequency fluctuation of signal reflected from passive dipole cloud for various phases of falling in calm atmosphere: a - 20 seconds after ejection, b - 3 minutes after ejection, c - 6 minutes after ejection, d - 10 minutes after ejection.

shows the time dependency of frequency spectrum of the reflected signal on the cloud of passive dipoles cut at $\lambda = 10$ cm.

From Fig. 9.3a it can be seen that with elaspsed time since the instant of the ejection the amount of the fluctuating component f_D in the total signal and hence also the width of the frequency spectrum of the jamming signal. Such a signal corresponds more to the creator of the interference since a) it covers a wider domain. and b) the component f_D contains a significant "mobile" component, which cannot be eliminated by simpler systems of selection of mobile targets.

It can be stated with rather good reliability that the distribution of the velocities inside the cloud of passive dipoles and hence their amplitudinal spectrum of frequency fluctuation approaches Gauss distribution. Thus can for different velocities of motion v_r be determined the width of frequency spectrum with

determined the width of frequency spectrum with

$$f'_D = \frac{5 v_r}{\lambda} \tag{9.14}$$

where: f'_D = spectral width in [Hz] at 3 db of maximal value

v_r = velocity of motion relative to radar in [cm/sec],

λ = radar wavelength in [cm].

The duration of the interference due to passive dipoles on radar screen depends on their falling velocity which, in turn, depends on the makeup of the dipole and atmospheric conditions. Passive dipoles must be made so that they have the smallest possible specific weight and so that they have the most appropriate aerodynamic shape, and that they are made of materials which are not hygroscopic, where the wetting effect is smallest, and which is sufficiently strong and elastic, so that the percentage of damaged or bent dipoles during ejection is minimal.

At the site where passive dipoles are employed, one must know the meteorological parameters of the atmosphere, namely:

- wind velocity in various layers of the atmosphere,
- vertical component of air currents,
- temperature in air layers, and
- atmospherilia type and quantity present (in rain or snow the falling velocity increases, and so does the wetting).

The falling velocity of aluminum foil passive dipoles 0.025 mm in thickness varies from 30 to 60 m/min. In the upper atmospheric layers it is higher, due to rarer air; in the lower layers it is smaller, due to denser air and increased upsky currents due to the heating of earth's surface.

Effective masking of true target will be achieved only in that case when the dimensions of the cloud formed are smaller, but at least equal to the volume space which radar beam encompasses during its pulse

duration at the distance where the cloud forms (Fig. 9.4):

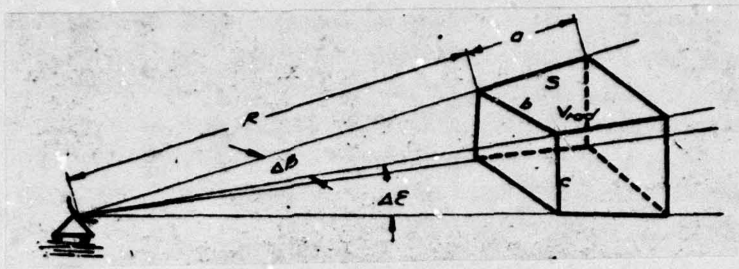


Fig. 9.4. Illumination geometry of passive dipole cloud.

On the basis of data from Fig. 9.4 we obtain:

duration of the pulse converted to length units

$$a = \frac{c \cdot \tau}{2} \tag{9.15}$$

azimuthal width of the beam at distance R

$$b = \frac{\pi \cdot R}{180} \cdot \Delta\beta \tag{9.16}$$

elevation width of the beam at distance R

$$c = \frac{\pi R}{180} \cdot \Delta\varepsilon \tag{9.17}$$,

where: τ = radar pulse duration in [sec],

c = velocity of light [mc/sec]

$\Delta\beta$ = antenna beam width with respect to azimuth in [°],

$\Delta\varepsilon$ = antenna beam width with respect to elevation in [o].

The total space volume occupied by radar beam of pulse duration τ at distance R amounts to

$$V_{rad} = a \cdot b \cdot c = 45{,}67 \cdot 10^{-6} \cdot R^2 \cdot \tau \cdot \Delta\varepsilon \cdot \Delta\beta \ [km^3] \tag{9.18}$$

where: R = distance to cloud in [km];

$\Delta\varepsilon$ and $\Delta\beta$= antenna beam width in [°];

τ = pulse duration in [μ/sec].

To the extent that here the dimensions of the cloud are larger than the space taken up by radar pulse, the desired radar reflex surface decreases to thatone which corresponds to the reflex surface of the occupied space. This surface will not be sufficient for masking the target. To prevent this, the volume of the passive dipole cloud must always be smaller than the volume of the space occupied by the pulse

$$V_{obl} \leq V_{rad} \qquad (9.19).$$

If passive dipoles are used against search radars where the elevation width of the beam is such that they spread over all altitudes, one must take special care that the passive dipole cloud is moved to the occupied horizontal surface S which according to Fig. 9.4 and equations 9.15 and 9.16 amounts to:

if

$$0 < \Delta\varepsilon < \sim 80^0,$$

then

$$S = a \cdot b = \frac{c\tau}{2} \cdot \frac{\pi \cdot R}{180} \cdot \Delta\beta = \qquad (9.20)$$

$$S = 2{,}61 \cdot 10^{-3} \cdot \tau \cdot R \cdot \Delta\beta \ [\mathrm{km}^2].$$

Example: using passive dipoles we wish to mask one or more airplanes with total radar reflex surface of the target σ_{cilja} = 10 m^2 at distance R = 100 km against radar with data: wavelength λ = 0.1 m, azimuthal beam width $\Delta\beta$ = 1°, elevation beam width $\Delta\varepsilon$ = 10°, radar pulse duration τ = 1 μsec.

length of passive dipole l equals to (according to 9.2):

$$l = 0{,}457\lambda = 0{,}457 \cdot 0{,}1 = 0{,}0457\ \mathrm{m},$$

number of passive dipoles n in the packet equals to (according to 9.10):

$$n = 1{,}3\ \frac{\sigma_{cilja}}{0{,}15\lambda^2} = 1{,}3 \cdot \frac{10}{0{,}15 \cdot 0{,}1^2} = 8650\ \mathrm{kom}$$

at distance R the dipole cloud must occupy a smaller space (according to 9.18)

$$V_{obl} < 45{,}67 \cdot 10^{-6} \cdot R^2 \cdot \Delta\varepsilon \cdot \Delta\beta \cdot \sigma = 45{,}67 \cdot 10^{-6} \cdot 100^2 \cdot 10 \cdot 1 \cdot 1 = 4{,}567 \text{ km}^3.$$

If the airplane from which the passive dipole packet is ejected flies directly at the radar station, the passive dipole cloud must be placed at smaller length (a from equation 9.15)

$$a_{obl} < \frac{c\tau}{2} = \frac{3 \cdot 10^{-8} \cdot 1 \cdot 10^{-6}}{2} = 150 \text{ m}$$

and smaller width (b from equation 9.16)

$$b_{obl} < \frac{\pi \cdot R}{180} \Delta\beta = \frac{\pi \cdot 100 \cdot 10^3 \cdot 1}{180} = 1{,}75 \cdot 10^3 \text{ m.}$$

If passive dipoles are made of aluminum foil 0.025 mm in thickness, 0.25 mm in width, and lengthwise cut by frequency, then - according to Schlesinger - one can obtain the necessary quantity of passive dipoles produced in kg from

$$\frac{\sigma \cdot f_r}{6600} = M \text{ [kg]} \tag{9.21}$$

where: σ = reflex surface desired to be attained in [m];

fr = radar frequency in [GHz];

M = band quantity in [kg].

9.1.2. INCREASED ATTENUATION OF ELECTROMAGNETIC WAVES IN A PASSIVE DIPOLE CLOUD

The electromagnetic waves passing through a passive dipole cloud become weaker. We shall attempt to determine the attenuation coefficient in a dipole cloud with concentration n of the dipoles per unit volume (1 m^3).

It can quite reliably be shown that attenuation in passive dipole clouds causes activation and secondary radiation. Therefore, the loss in the

passing energy is proportional to the number of dipoles per unit volume which, in turn, is proportional to the specific radar reflex surface (σ_{sp}) of the same volume (geometry in Fig. 9.5).

$$dP = -P \cdot \sigma_{sp} \cdot dy \tag{9.22}$$

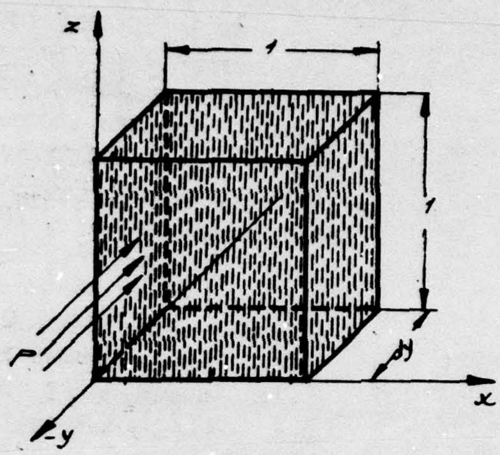


Fig. 9.5. Geometry of unit volume of dipole cloud.

where: dP = power loss per unit volume;

P = incoming power at boundary surface;

$\sigma_{sp} = \frac{\sigma_{obl}}{V_{obl}}$ = specific radar reflex surface per unit volume in $\left[\frac{m^2}{m^3}\right]$.

The specific radar reflex surface per unit volume is equal to (according to expressions 9.6 and 9.7)

$$\sigma_{sp} = n\,\sigma_0 = n \cdot 0{,}15 \cdot \lambda^2 \tag{9.23}$$

where: n is the number of passive dipoles per unit volume.

Using equation (9.23) one can write equation (9.22) in the form

$$\frac{dP}{dy} + P \cdot n \cdot 0{,}15\,\lambda^2 = 0 \tag{9.24}$$

By integrating equation (9.24), using boundary conditions $P = P_0$ at $Y = 0$, the power loss at passage through cloud of width y meters is

$$P = P_0\, e^{-n \cdot 0.15 \lambda^2 y} \tag{9.25}$$

where: P_0 is the power at the start of beam entry into the cloud.

From equation 9.25 is obtained attenuation coefficient β_s for one-sided passing of electromagnetic waves through a passive dipole cloud

$$\beta_s = 0{,}815 \cdot \lambda^2 \cdot n \ [db/m] \tag{9.26}$$

where: λ = wavelength in [m];

n = dipole number in [pieces].

Example of application:

If one wants to attenuate a beam of electromagnetic waves with wavelength $\lambda = 10$ cm for 20 times by a passive dipole cloud with length y = 1 km, one must introduce into the path a cloud with the attenuation

$$\beta = 10 \log 20 = 13\ db$$

attenuation coefficient being

$$\beta_s = \frac{\beta}{y} = \frac{13}{1000} = 0{,}013\ db/m$$

and one can calculate the required number of dipoles per 1 m^3 using equation (9.26)

$$n = \frac{\beta_s}{0{,}815 \cdot \lambda^2} = \frac{0{,}013}{0{,}815 \cdot 10^2} = 160 \text{ pieces}/m^3$$

The more twofold passing of electromagnetic energy is present in the problem at hand, the more is attenuation considered to be twofold also.

This countermeasure can effectively be attenuate or even completely block a number of electronic installations, such as radars and radio relay communications. It is understandable that their duration is associated with the falling rate. The effectiveness increases at shorter wavelengths. For the same example as cited above, but at the wavelength $\lambda = 3$ cm we obtain

$$n = \frac{0{,}013}{0{,}815 \cdot 9 \cdot 10^4} = 17.7 \text{ pieces/m}^3$$

which is more and from the standpoint of economy quite attractive.

9.1.3. TACTICAL APPLICATION OF PASSIVE DIPOLES

a - <u>Creation of a corridor</u>

The optimal way of creating this countermeasure is if the airplane jammer (OM) flies following a determined march-route and throws the passive dipole packets in the direction in which it flies within time interval t, which is smaller and at the most equal to the capability of separating the radar station against which the measure is undertaken. The situation in air is presented in Fig. 9.6.

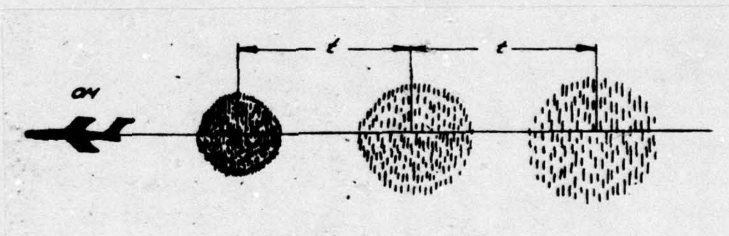


Fig. 9.6. Creation of a corridor.

The capability of separating the radar station of beam width $\Delta\beta$ at distance R and pulse duration τ is shown in Fig. 9.7. The time intervals of throwing out passive dipole packets t must be smaller or equal.

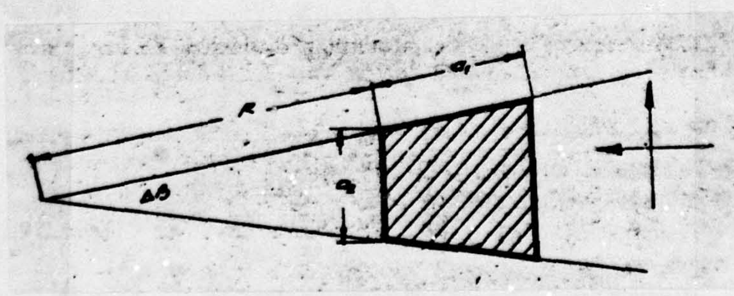


Fig. 9.7. Separation of radar station.

$$a_1 = \frac{c\tau}{2} \quad \text{and} \quad a_2 = \frac{\pi \cdot \Delta\beta}{180} \cdot R$$

For direct flight on radar:

$$t_u = \frac{a_1}{v} = \frac{c\tau}{2v}$$

or

$$t_u = 150 \frac{\tau}{v} \; [\text{sec}] \tag{9.27}$$

for parallel flight:

$$t_p = \frac{a_2}{v} = \frac{\pi \cdot \Delta\beta \cdot R}{180 v}$$

or

$$t_p = 17{,}5 \frac{\Delta\beta \cdot R}{v} \; [\text{sec}] \tag{9.28}$$

where:

τ = radar pulse duration in [μsec];

v = airplane velocity OM in [m/sec];

R = distance in [km];

$\Delta\beta$ = azimuthal width of radar beam in [$^\circ$].

Depending on the flight--radar itinerary relationship, the individual ejection times of the packet also vary (t_u or t_p). To obtain the number of the packets which must be ejected in one flight, the entire itinerary is divided into sections which correspond to direct or parallel flight and these are then divided into lengths a_1 or a_2 and vice-versa. Due to very short times t_u in case of radars with a short pulse, and t_p in case of radars with a narrow beam, installations for rapid ejection of the packet are being built into airplanes jammers. These installations are in case of fast airplanes equipped additionally for fast dispersion of the packet into the cloud.

The corridor can expand to the left, to the right, above, or below the itinerary route of the jammer airplane if the corresponding missiles equipped with passive dipoles are used and fired in time intervals t_u

and t_p. which correspond to the firing direction of the missile and the flight direction of the jammer airplane.

b) <u>Increased attenuation on the radar--target--radar relation</u>

If an artificial and very dense passive dipole cloud forms between the radar and the targets which the radar must reveal, two effects appear: such false echoes form which are capable of saturating the radar receiver and, what is even more important, attenuate the radar beam by densely distributed reflection elements on the radar--target--radar path (point 9.1.2. on p. 230 of copy)
This method is very effective against radars with short wavelengths

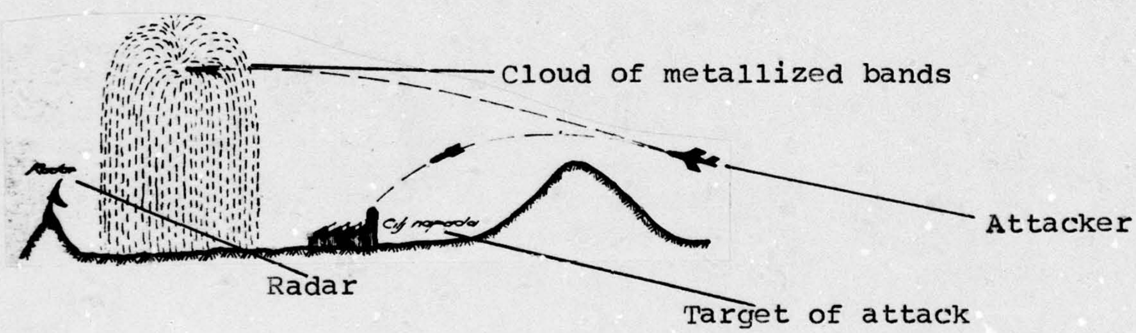


Fig. 9.8. Creation of artificial cloud on radar--target--radar path.

(region S and X). To understand the application of this method, here are some tactical examples.

First case: Attack airplane ejects in front of itself in the direction of the radar a missile filled with passive dipoles, which after the explosion of the missile (projectile) form an artificial cloud of sufficient density. The dipole cloud formed considerably enhances attenuation on the route and thus becomes the means for screening the action. The attack airplane can undisturbedly finish the assignment. This situation is approximately shown in Fig. 9.8.

Second case: Preventing the operation of two radars which guard the target of the attack. The successive development of the situation is given in Fig. 9.9, a, b, and c.

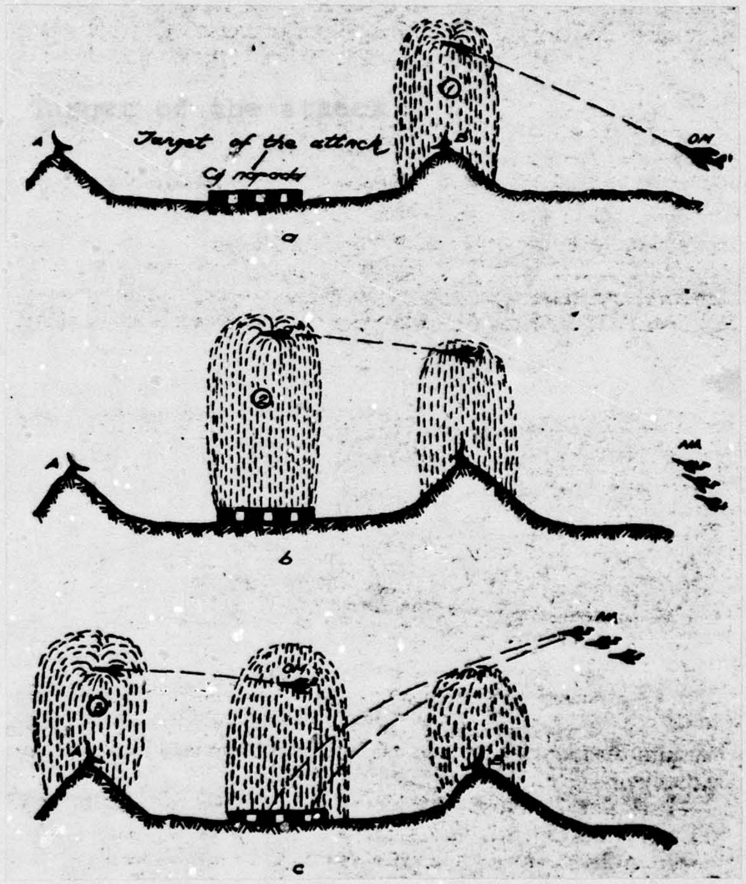


Fig. 9.9. Preventing the operation of two radars by creation of artificial clouds..

In front of the strike group of airplanes NA which will carry out the attack is the airplane jammer OM whose mission is to block radar stations A and B. By firing of the first rocket (1) filled with passive dipoles from a safe distance and its explosion above radar station B, a cloud

forms above the station in the form of an umbrella. The possibility of being detected by radar A is thereby considerably decreased, the cloud represents a false echo and increased attenuation, while for radar B the cloud represents an obstacle with increased attenuation. Airplane jammer OM gets unhindered to the first cloud, fires rocket (2) and creates a cloud above the target of the attack. The cloud serves for its own masking and, when it gets to it, fires rocket (3). When this one explodes, a cloud forms above radar station A and makes its operation impossible by an identical way to cloud (1) and radar station B. During the entire duration of the operation, if the dipole concentration in the cloud was sufficient, neither airplane jammer OM nor strike group NA were detected by radars A and B.

Radar observer on radar B observed only cloud 2 and 3 as an intensive and spatially large echo, whereas cloud 1 which as a matter-of-fact prevented its detection was not observed. This is so because its distance from the radar is small and it is located at a distance which corresponds to the duration of its transmitting pulse and recovery time of the receiver.

c) <u>Simulation of radar echo by means of a cloud of metallized bands and response techniques</u>

By a combination "corridor" ejection of passive dipoles and using clouds-piles as passive reflectors for airplane responder (transponder or repeater type), a very effective countermeasure is obtained, which can, as desired, produce resting, approaching, or moving away false targets. Using this method, airplanes can effectively be masked on the characteristic mission against all radars which make use of - in some way - the doppler effect (for the selection of mobile targets, for velocity determination, etc.) or form a large number of false

echoes and thereby saturate the enemy search system.

The situation in the air can be the following. Airplane jammer (OM) with in-built installation for ejection of the passive dipole packet in time intervals and active responder moves in path (a) which is parallel to path (b) of the principal target (GC) which must be protected by false echoes (Fig. 9.10).

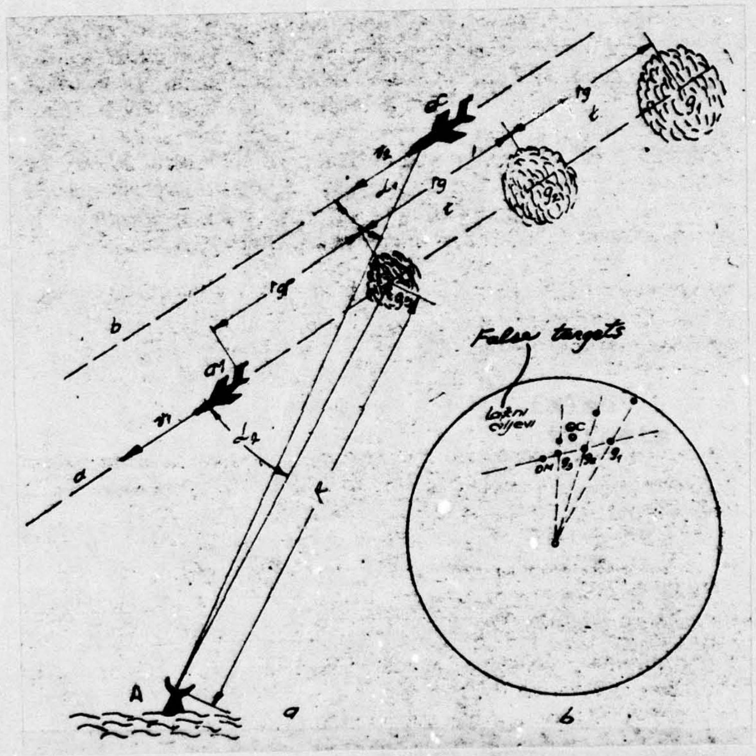


Fig. 9.10. Simulation of radar echo by means of passive dipoles and active responders: a - situation in space, b - echoes on indicator (OM - airplane jammer, GC - airplane principal target, g_1, g_2, g_3 - passive dipole piles, LC - false echoes).

Airplane jammer ejects passive dipole packets ineequal time period t. Relative to airplane velocity of motion, clouds can be formed from the ejected passive dipole packets being resting ones. These "resting"

passive dipole clouds are used as large passive reflectors moved into space.

If now the artificial passive reflectors are used for the reflection of the signal on the radar--cloud--airplane--responder--cloud--radar route, then as suitable selection of the responder can be simulated the desired distance and change in the distance, desired speed and change in the speed, desired doppler effect and its change, phase change, all individually and together.

Airplane jammer OM ejects passive dipole packets backwards, at a speed which is equal to its traveling speed v_1. The dipole packets disperse and form in space successive resting clouds--piles g_1, g_2, g_3 ..... at the mutual distance r_g. The positioning of airplane target GC and jammer OM on paths a and b and the ratio of their velocities v_1 and v_2 must be such that airplane OM is always in front of airplane GC at such a distance which is necessary that airplane GC would be constantly screened by piles g_3, g_2 ... With respect to that piles g_1, g_2, and g_3 ... fall, and this very slowly relative to the velocity of the airplane, they can in the following be considered resting with respect to ground radar located at point A.

The following data are known about airplane jammer OM:

- intrinsic flight velocity .. v_1;
- velocity of airplane which is screened ... v_2;
- distances between piles ... r_g;
- distance between jammer OM to the last pile .. r_{gr};
- approximate data regarding the angle between airplane GC and radar path .. α_1.

Such a combination of airplanes and clouds-piles of passive dipoles creates also common echoes, as a result of reflecting also from the airplane and the passive dipole cloud. We shall not discuss these. In the final analysis they only create even greater confusion on the radar indicator due to simultaneous display with simulated echoes.

How do occurrences on radar (A)--last pile (g_3)--airplane OM route with active responder look like? The transmitting signal from radar A arrives at pile (g_3) and becomes reflected from it in all directions. The receiving antenna of the responder on airplane OM receives this signal; in the receiver it becomes amplified and is readied for transmission. Transmission can be done with changed time, changed phase, and changed frequency relative to the received radar signal. The thus corrected signal is emitted by the transmitter in the direction of the last pile (g_3), from which a part of the energy is reflected in the direction of radar (A). On the radar screen this signal is displayed as a false target in the direction radar--pile g_3, with a different rate of motion along this direction. Inasmuch as in the reflection of radar signal and transmitted signal of the responder on airplane OM all piles g_1, g_2, g_3 ... take part, with the illumination rhythm of the ground radar, the airplane GC is becoming surrounded with a large number of fast and in all directions mobile false echoes.

1. Changing the emitting time of the reverse pulse creates the impression of a mobile target, which either moves away or approaches along the radar-pile line.

Without change in time, the false target shows up on radar A at the distance

$$R_0 = R + r_{gg} \tag{9.29}$$

As with the flight of airplane OM the distance to the last pile r_{gp} steadily increases, the distance to the false target also thereby increases. The traveling time of radar signal at individual sections of the travel path amounts to

$$t_o = t_R + t_{grp} + t_{grp} + t_R = \frac{R}{C} + \frac{r_{gp}}{C} + \frac{r_{gp}}{C} + \frac{R}{C} \tag{9.30}$$

where: C = velocity of light

R and r_{gp} = radar--pile distance relative to pile--airplane distance.

Time t_{rgp} steadily increases due to increased distance r_{gp}. If additional time change is introduced into the reverse pulse, the reverse signal prior to or later than t_o is obtained, which means at a greater or smaller distance from R_o. The traveling time of the radar signal for the false target is ($t_o \pm \Delta t$).

$$t_{LC} = t_R + t_{rgp} \pm \Delta t + t_{rgp} + t_R = 2t_R + 2t_{rgp} \pm \Delta t \tag{9.31}$$

which corresponds to the distance of the false target on radar A

$$R_{LC} = R + r_{gp} \pm c \cdot \Delta t \tag{9.32}$$

where the plus sign signifies moving away from radar, and the minus sign signifies the approaching to the radar.

2. By introducing the change in frequency into the reverse signal, such that corresponds to doppler frequency change, one can - due to the velocity of the searched target - simulate the fast, slow, and resting target, as well as the target with the opposite velocity. The doppler frequency change of the receiving signal of the radar for a mobile target is given by the expression (see equa. 9.11-9.13)

$$\Delta f = \frac{2 f_{rad}}{c} v \cdot \cos \alpha \tag{9.33}$$

where: v = velocity of mobile target;

f_{rad} = frequency of the transmitting signal of the radar;

c = velocity of light;

α = angle between target velocity vector and direction on radar;

2 = because of radar--target--radar path.

From this equation it can be seen that the change in the frequency is the higher the higher is the radial component of the velocity (component in the direction of the radar). Simulation of radial velocity $v\cos\alpha$ is made difficult due to constant change in angle α. Therefore, henceforth the velocity v will be simulated.

Ground radar illuminates the pile, the signal becomes reflected on account of airplane OM and arrives at the receiver of the responder with a change in frequency:

$$\Delta f_1 = -\frac{v_1}{c} f_{rad} \qquad (9.34)$$

(where the negative sign indicates the moving away of the airplane OM from the stationary pile).

If a responder (of the "transponder" type) is located on the airplane, which is so constructed that it responds on the same frequency by which it is incited, the receiving signal on the ground radar produces an impression of the target which moves away from the radar along the radar--pile line, at a velocity v_1 of airplane OM. The distance R_o at which the echo appears is the same as in the preceding case and corresponds to the sum of the distances radar--pile--airplane

$$R_0 = R + r_{gp} \qquad (9.35)$$

The distance increases at the same tempo as the distance between the last pile (g_3) and airplane OM (r_{gp}) increases.

If a responder (of the "repeater" type) is located on airplane OM, which is capable of introducing changes in electrical characteristics of the response signal, different effects can also be produced.

The resting target effect is achieved if in the response signal of the responder the doppler change in the frequency is compensated, so that the response frequency (on the basis of 9,34) amounts to

$$f_{odg} = f_{rad} + 2\Delta f_1 = f_{rad}\left(1 - \frac{2v_1}{c}\right) \qquad (9.36)$$

The twofold change in the equation is due to the twofold path of electromagnetic waves on the radar--target--radar path.

The direct motion illusion effect on the radar with increased velocity is obtained if the response frequency upon successive pulses changes by the amount which is higher than the doppler change

$$\Delta f_{odg} = \frac{2 f_{rad}}{c}(v_1 \cos\alpha + v)$$

where: v_1 is the airplane speed and v is the additional speed of the simulation.

If, however, one assumes that the radial component of the velocity of OM is equal to v_1 and if it is desired that the false target approaches by at least twofold velocity, then the magnitude of the additional velocity v must be such that it compensates for the illusion of moving away and that it creates the desired impression. Thus, the velocity v for the case of twice faster approching must be

$$v \geqslant 3v_1$$

The correction only by the doppler change introduces contradictions into false echoes, especially in case of radars which use the doppler effect for the determination of the velocity, and the measurement of

time for the determination of the distance. False echoes in such radars appear at locations which in no way correspond to their velocity. Such contradictions are very appropriate in countermeasures since they confuse the users of manual or automatized systems.

Combining both systems makesit possible to so attune the changes in the time Δt and frequency Δf that in every which way they correspond to real targets.

The power of the false echo at the site of the ground radar must be such that it corresponds to the power of the receiving signal of the true target of these dimensions. Since the power of the receiving signal from the true target varies with $\frac{1}{R^4}$, the responding installation must have such an automatic possibility of changing the output power in dependence of the distance that the amplitude of its signal reflected from the pile will always be such which the true target has on this simulated distance.

9.2. MODULATION OF RADAR ECHO

With respect to the technical principles used the modulation of true radar echo belongs to intentional passive countermeasures, whereas according to the effect which they achieve, it also belongs to imitation groups. The purpose of this countermeasure is the imitation of malfunction on radar installation, and it is employed against radars which use the successive direct-signal zone for automatic guidance by angular coordinates (all kinds of radars with conical searching). The method of determination of target coordinates by direct-signal zone is based on successive comparison in the amplitude of the receiving signal from all four quadrants and on the directing of the antenna into the zone where all 4 signals are amplitudinally equal.

By building in a passive reflector on the aircraft, its radar echo at a certain angle between the radar beam and the reflector significantly increases, while at some other angle it remains unchanged. If the passive reflector rotates with a circular velocity ω, the total radar reflex surface of the aircraft varies according to

$$\sigma_{uk} = \sigma_{av} + \sigma_{pr} \cdot \cos \omega t$$

where: σ_{uk} = total reflex surface of the airplane;

σ_{av} = reflex surface of the airplane;

σ_{pr} = maximum reflex surface of passive reflector;

ω = $2\pi r$ = angular velocity of turning of passive reflector;

n = number of turns per second.

The change in the total reflex surface causes also a similar change in the receiving signal on the radar

$$P_{prij} = \frac{P_t \cdot G^2{}_{rad} \cdot \lambda^2}{(4\pi)^3 \cdot R^4} \cdot (\sigma_{av} + \sigma_{pr} \cdot \cos \omega t)$$

By correct selection of the type and the size of the passive reflector, its position on the airplane, and the number of turns, the optimal amplitudinal modulation of the intrinsic echo is obtained.

Against radars with conical searching, a suitable turning rate is between 30 and 50% of the number of turns of the eccentric antenna beam which forms the searching conus of the space.

Passive reflector is selected according to the following criteria:

- that it has a high reflex surface with respect to its size and weight;

- that the maximum reflex surface is equal to or larger than the reflex surface of the airplane, and

- that the reflex surface is approximately constant in the probable angles of illumination.

The mounting of the passive reflector on the airplane and the selection of its axis of rotation is done so that for the most probable directions of illumination of the airplane the reflex surface of the passive reflector per each turn gives one or more paths of the reflex surface of the airplane (Fig. 9.11)

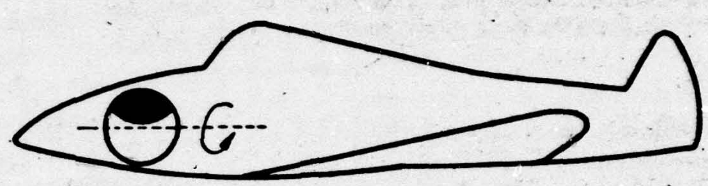


Fig. 9.11. Mounting of passive reflector in airplane's nose.

This countermeasure is demonstrated on the radar as a very instable servo-system type for moving the antenna by angular coordinates. The user immediately thinks of malfunction in the installation and undertakes measures for its elimination. As countermeasure is used the switching off of the automatic system and the conversion to manual system of operation or to some other (lower) operational frequency, if this is possible by the construction of the installation. Mono-pulse radars cannot be jammed this way.

X CHANGE IN RADAR REFLEX SURFACE OF THE OBSERVED OBJECT

Using passive reflectors of various shapes and absorption or diffusion materials of various compositions, effects of increasing, decreasing, or changing the shape of the radar reflex surface of individual targets or their groupings can be obtained, thereby changing the impression which these targets by their intrinsic reflex surface produce on radar indicators. Since every technique serves a specific purpose, and since their application in recent times is high, it is necessary that each effect and the means which produce it be specially treated.

10.1. INCREASING RADAR REFLEX SURFACE

Basically there are two techniques of this increasing:

- application of an amplifier - retranslator of primary signals on target object, and
- application of passive reflectors of various shapes.

The methods used for increasing the radar reflex surface have a two-fold application: first, to provide false radar targets--mommies of physically small sizes (pilotless aircraft, missiles) with reflex surfaces which correspond to the targets which are to be simulated and, secondly, to partially increase the surface of uniform reflex surfaces of ground objects (roads, airport runways, rivers, and similar) and thereby achieve their drowning in (blending with) the whole, thus creating masking effects (see point 10.3).

10.1.1. PASSIVE REFLECTOR

Even surface

Even surface is one of the most effective passive reflectors when it is at the right angle to the beam of incoming waves. Its radar reflex surface can be very large if its geometrical surface is large relative to the wavelength. One serious shortcoming is the great dependence of the reflection diagram on the angle of incidence; even small changes in the angle significantly decrease the effectiveness of the reflecting. Inasmuch as even surface is a component part of almost all angular passive reflectors, but also a part of the reflex surface of the object under observation (sea surface, lakes, roads, runways, and similar), one must, at least in essential outline, know its reflecting properties.

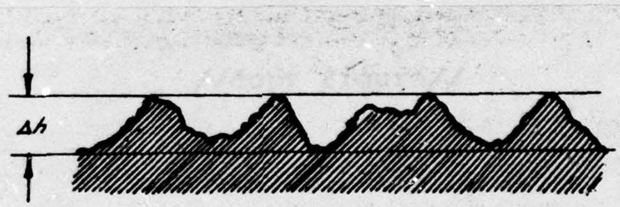


Fig. 10.1. "Roughness" of terrain.

Under even surface one understands every smooth surface where "roughness" (Fig. 10.1) is smaller or equal to

$$\frac{\Delta h}{\lambda} \leqslant \frac{1}{10} - \frac{1}{16} \qquad (10.1)$$

Every surface which has such or smaller "roughness" represents a very good reflector and reflects electromagnetic waves similarly to how a mirror reflects light waves. The approximate "roughness" values for individual wavelengths are given in Table 10.1. From this table it can be seen that many configurations on the terrain represent in their geometrical properties an ideal reflector. The reflecting properties

AD-A083 358 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/4

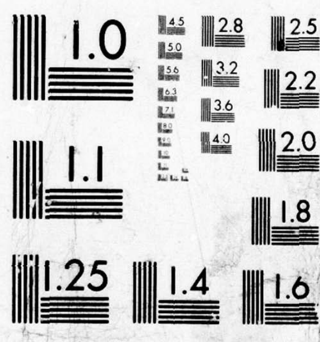
ELECTRONIC COUNTERMEASURES,(U)

AUG 79 A RAZINGAR

UNCLASSIFIED FTD-ID(RS)T-0498-79 NL

4 OF 5

AD A083358



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

of these surfaces which are equal in regard to their geometrical properties lead to that the reflected signals differ from one another.

λ (cm)	Δ h (mm)
3	3—1,87
10	1 —6,25
24	24—15
55	50—31,3

Table 10.1. Approximate "roughness" values for various wavelengths.

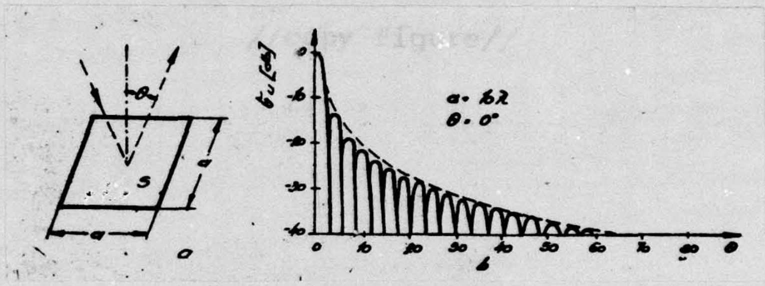


Fig. 10.2. Even surface as reflector: a - illumination geometry: b - reflection diagram of even surface for a = 10λ and θ= 0°.

The radar reflex surface of an even surface is given by expression (see point 11.1 on p. 285 of foreign copy and point 11.1.1 on p. 286 of foreign copy).

If the angle of incidence, Θ= 0

$$\sigma = \frac{4\pi S^2}{\lambda^2} \qquad (10.2)$$

(where S = a•b)

Fans (see Fig. 10.2a) appear in the reflected radiation diagram, whose number is

$$n = \frac{8a}{\lambda}$$

and the width of the principal fan is $\theta = 0^{\circ}$

$$\Delta = \frac{\lambda}{a}$$

The maximal reflex surface is at angle of incidence. If this angle of incidence is increased, the reflex surface is considerably decreased (see equations 11.7-11.11 on pp. 286-290 of copy)

Thus for

$$\theta = 2{,}5^{\circ} \quad \sigma \approx 0{,}42\ \sigma_{max}$$
$$\theta = 4^{\circ} \quad \sigma \approx 0{,}06\ \sigma_{max}$$

This fact that the optimum of the reflection is at $\theta = 0^{\circ}$ significantly simplifies the calculation of all angular reflectors, Thus the radar reflex surface of an angular reflector

$$\sigma = \frac{4\pi}{\lambda} \cdot S^{2}_{ef} \qquad (10.3)$$

where S_{ef} is the effective surface of angular reflector, i.e. the surface of the plane obtained by projection of active part of the angular reflector on the level of the front of the incident rays.

<u>Bilateral passive reflector</u>

Bilateral passive reflector is one of the simplest angular reflectors quite widely used in recent wars for the creation of artificial objects on the high seas and on lakes. It is composed of two even surfaces cut at an angle of 90°. The ray which falls onto one side of the reflector reflects from it and falls onto the other, from which it is again reflected and returned into the direction from which it came (Fig. 10.3a).

The maximum reflex surface of one-fourth of the bilateral passive reflector is obtained when the incident rays are in the <u>xy</u>-plane and

when the angle formed by the rays and the side amounts to 45°. In

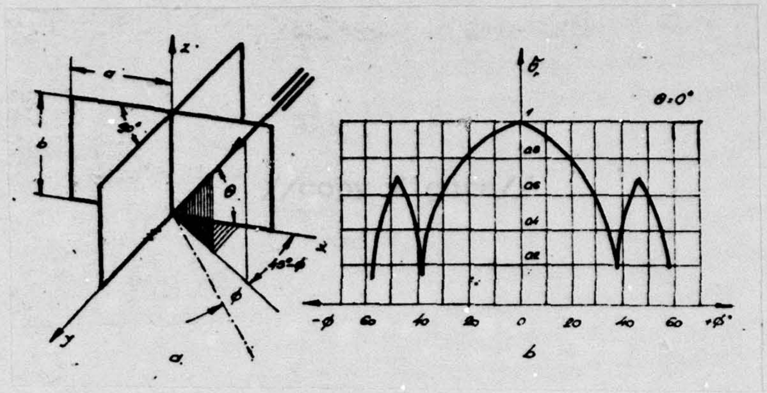


Fig. 10.3. Fourfold bilateral passive reflector: a - illumination geometry, b - diagram of reflecting of one-fourth of passive reflector in horizontal direction.

the case when illumination geometry as shown in Fig. (10.3a) is used, the angle is $\Phi = 0°$. Then the reflex surface is maximal and amounts to

$$\sigma_{max} = \frac{8\pi \cdot a^2 \cdot b^2}{\lambda^2} \; [m^2] \qquad (10.4)$$

if a and b the height and the width of the side and λ the wavelength of the illumination are expressed in m.

The reflector has four maxima, namely at $\Phi = 0°$, 90°, 180°, and 270°, which decrease by changing the angle Φ. In case of the angle of incidence $\Phi = 45°$ from the maximal value (0, 90, 180, 270°) the reflector acts as an even surface of magnitude a.b.

Trilateral passive reflector with square sides

By adding a third side to the bilateral angular reflector, its vertical characteristics of the reflection improves.

The reflex surface - and thereby also the reflected signal - depends on the position of the reflector relative to the source of the rays

which - when the angles which subtends the direction of the ray in the azimuthal and elevational plane are equal - results in $\Theta = 45^o$ and $\Phi = 0^o$. Then the reflex surface is maximal and amounts to

$$\sigma_{max} = \frac{12\pi a^4}{\lambda^2} \tag{10.5}$$

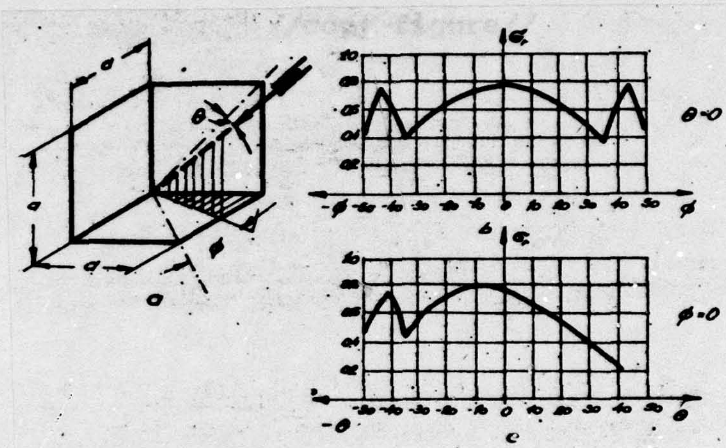


Fig. 10.4. Trilateral reflector with square sides: a - illumination geometry, b - reflection diagrams.

When incident rays deviate from optimal angles, the result is a decrease in the reflex surface (see diagram b and c on Fig. 10.4). This for the deviation of 15°, the reflex surface is decreased to 58%, and for a deviation of 24° already to 17% of the maximal value.

Trilateral passive reflector with triangular sides

This is the most commonly used passive reflector in radar technology. The maximal reflex surface is

$$\sigma_{max} = \frac{4\pi a^4}{3\lambda^2} \tag{10.6}$$

Passive trilateral triangular reflector with sides a = 1 m and at the wavelength λ = 10 cm has the maximum reflex surface σ_{max} = 420 m^2

which corresponds to the surface of larger targets (ships). This same reflector but at $\lambda = 3$ cm already has a surface of 4660 m^2.

Trilateral passive reflector with circular sides

Maximal reflex surface amounts to

$$\sigma_{max} = \frac{16}{3} \frac{\pi a^4}{\lambda^2} \qquad (10.7)$$

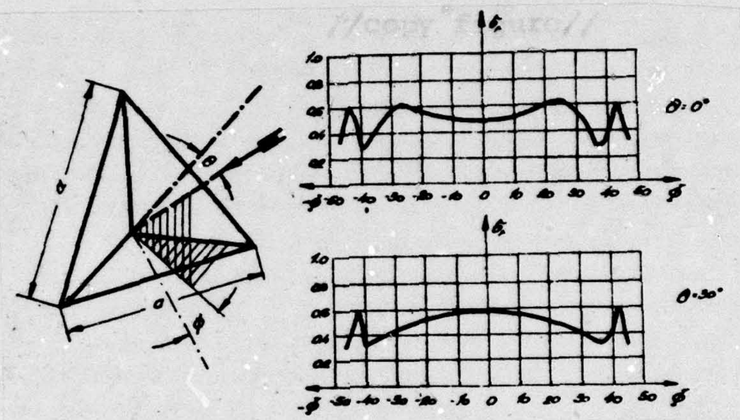


Fig. 10.5. Trilateral reflector with triangular sides.

The reflex surface calculated using equations (10.4 to 10.7) requires that the sides be made very accurately due to the angle between the sides on which reflection depends. Each deviation in the angle of inclination of the sides, especially in large reflectors (large $\frac{a}{\lambda}$ ratio) considerably decreases the effectiveness of the reflector. For trilateral angular reflectors this decrease is given in Fig. 10.7. In large reflectors $\frac{a}{\lambda} = 20-60$, the maximum deviation $\Delta = \pm 0.5-1^{\circ}$ is allowed.

If reflex surfaces of individual types of trilateral passive reflectors (equations 10.5, 10.6, 10.7) are compared, it can be seen that the

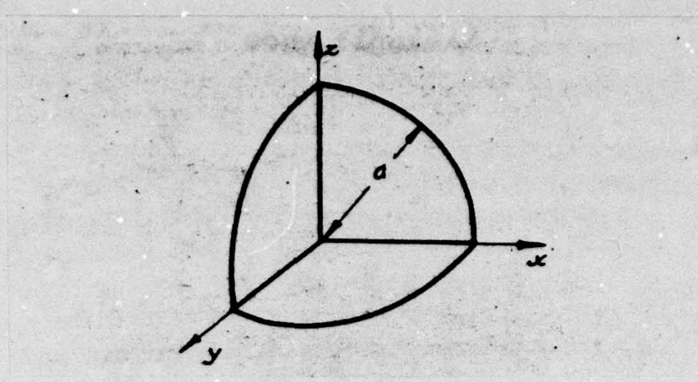


Fig. 10.6. Trilateral passive reflector with circular sides

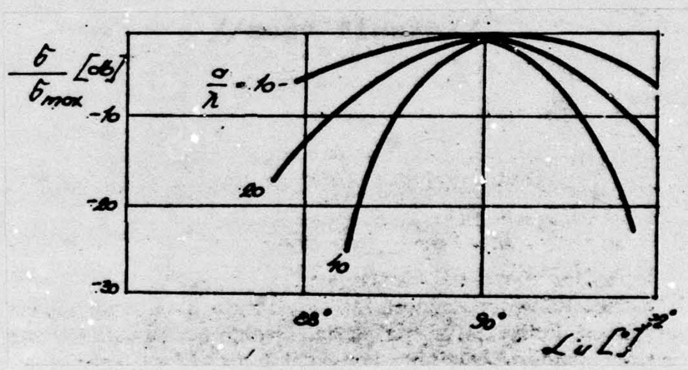


Fig. 10.7. Dependence of the reflex surface on the magnitude of the reflector and the accuracy in the making of the angle between the sides.

the maximal reflex surfaces of the reflector with equal sides relate as

$$\sigma_{\Delta} : \sigma_{\bigcirc} : \sigma_{\square} = 1:4:9 \tag{10.8}$$

If the used quantities of the material for the fabrication, or better, their weight (t) are put into the relation, then one obtains

$$t_{\Delta} : t_{\bigcirc} : t_{\square} = 1:1{,}57:2 \tag{10.9}$$

From expression (10.8 and 10.9) it can be seen that the weight of the passive reflector does not rise proportionately to the reflex surface.

This fact must always be taken into consideration in the selection of the proper reflector for a particular purpose.

Inasmuch as the distance at which the specific radar installation will discover the passive reflector (R) depends on its reflex surface (σ) , and since the latter depends on the magnitude of its sides (a), one can write

$$R = K_1 \sqrt[4]{\sigma} = K_2 \sqrt[4]{a^4} = K_2 a \qquad (10.10)$$

(where: K_1 is the radar installation constant, and K_2 is the passive reflector constant).

From the relation (10.10) it is seen that the visibility of the passive reflector is directly dependent on the magnitude of the sides and that if the reflector with sides 1 m is seen at a certain distance, the reflector with twofold sides will be seen at the twofold distance.

From the relation of the reflex surfaces (equation 10.8) one can find the distance of discovering various types of reflectors

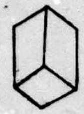
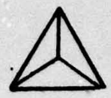
$$R_{\triangle} : R_{\bigcirc} + R_{\square} = 1 : 1{,}414 : 1{,}732 \qquad (10.11)$$

In Table 10.2 are given the maximal reflex surfaces of simple angular reflectors as a function of their shape, side magnitude, and wavelength.

Groups of passive angular reflectors

The fundamental deficiency of the trilateral triangular reflector is the high dependency of its reflex surface on the illumination direction by radar beam (angles Θ and Φ). From diagrams in Figs. 10.3, 10.4, and 10.5 it can be seen that the reflector can be used at most at 80° by azimuth and 50° by elevation.

Table 10.2. Maximal reflex surfaces of angular passive reflectors, as a function of their shape, size, and wavelength.

$\lambda_{[m]}$ / $a_{[m]}$	 $\sigma = \frac{\sigma = 12 \cdot \pi a^4}{\lambda^2}$ [m²]			 $\sigma = \frac{4\pi a^4}{3\lambda^2}$ [m²]			 $\sigma = \frac{16}{3} \cdot \frac{\pi a^4}{\lambda^2}$ [m²]			Kugle $\sigma = \pi R^2$ [m²]
	0,03	0,1	0,24	0,03	0,1	0,24	0,03	0,1	0,24	
0,2	66,6	6	0,108	7,4	0,667	0,0119	28,1	2,56	0,046	0,1256
0,4	1040	94	1,68	117	10,5	0,188	458	41,7	0,745	0,502
0,6	5260	485	8,75	600	54	0,97	2380	216	3,88	1,131
0,8	$17{,}2 \cdot 10^3$	1550	28	1910	171	3,06	7550	685	12,3	2,545
1	$42 \cdot 10^3$	3790	68	4660	420	7,55	$185 \cdot 10^2$	1680	30,1	3,142
1,5	$213 \cdot 10^3$	19100	344	$23{,}4 \cdot 10^3$	2120	38	$93 \cdot 10^3$	8450	151,5	7,069
2	$673 \cdot 10^3$	60600	1090	$74 \cdot 10^3$	6720	121	$297 \cdot 10^3$	$27 \cdot 10^3$	484	12,57
3	$34 \cdot 10^5$	$3{,}10^5$	5500	$374 \cdot 10^3$	$34 \cdot 10^3$	610	$1498 \cdot 10^3$	$136 \cdot 10^3$	2440	28,27
5	$263 \cdot 10^5$	$22{,}7 \cdot 10^5$	42700	$29 \cdot 10^5$	$26{,}3 \cdot 10^4$	4720	$113 \cdot 10^5$	$103 \cdot 10^4$	18400	78,54
10	$42 \cdot 10^7$	$379 \cdot 10^5$	$68 \cdot 10^4$	$463 \cdot 10^5$	$42 \cdot 10^5$	75500	$185 \cdot 10^6$	$168 \cdot 10^5$	301000	314,2
15	$212 \cdot 10^7$	$191 \cdot 10^6$	$34{,}4 \cdot 10^5$	$233 \cdot 10^6$	$212 \cdot 10^5$	$38 \cdot 10^4$	$93 \cdot 10^7$	$845 \cdot 10^5$	$1515 \cdot 10^4$	706,9

Regarding that passive reflectors are used for masking of objects and that one can never be precisely sure from which side they shall be illuminated, a combination is built, namely a group of passive angular reflectors. Which combination at the given moment shall be used depends on the type of radars against which it is being used. Thus, e.g., against ship radars one uses a combination which has an equalized radiation diagram along the azimuth, whereas against airplane radars an equalized radiation diagram both along the azimuth and along the elevation is needed, or at least, under the elevation and azimuthal angles of probable illumination.

The most widespread and known are constructions of 5 or 6 cells in a single group of passive reflectors. Cells can be formed by angular reflectors with triangular, circular, and square sides, and can be set up under various angles, from out of which the right angle to the incoming rays is the most inconvenient case. The resulting diagram of the reflecting of the group shows large variations in the reflex surface (highly pronounced maxima and minima). In the directions of the minimum of the reflex surface the effectiveness of the group of passive reflectors is minimal, which must be taken into consideration in their practical applications.

In Figs. 10.7-10.10 can be seen the dependence of the reflex surface on various combinations of the cells. The most favorable combination is an eight-cell reflector as pictured in Fig. 10.8b, which has many minima, and which on the whole gives an almost uniform signal along the azimuth. The more this combination is refined, the more a favorable or most favorable diagram is obtained (Fig. 10.9). The rate of turning depends on the pulse frequency and the rate of search by the radar and it is so selected that during the time that the radar beam is focused on the reflector this same reflector turns at least one complete turn.

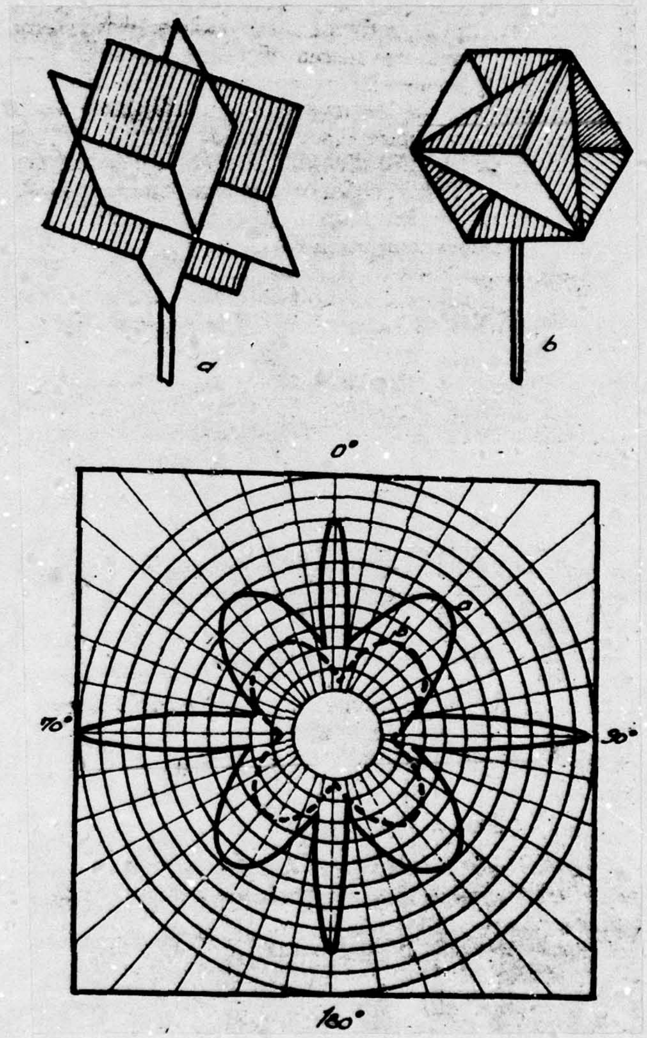


Fig. 10.7. Group eight-cell reflector: distribution of cells under an angle of 90° with respect to the vertical: a - cell with rectangular sides, and b - cells with triangular sides.

A group of five cells with triangular sides arranged in a circle provides a uniform reflex surface diagram in contrast to the one for the eight-cell group (Fig. 10.10). Such a group is formed by individual cells, whose symmetry axes are oriented in the horizontal plane under mutual angles of 72°.

Biconical passive reflector

In contrast to the trilateral passive reflector, the biconical passive reflector has in the horizontal plane a uniform reflection diagram (Fig. 10.11).

The reflex surface corresponds to the cylinder with mean diameter $d = \frac{d_1+d_2}{2}$ and height h and in case of $\theta = 0°$ amounts to

$$\sigma = \frac{\pi \cdot h^2 \cdot (d_1+d_2)}{\lambda^2} \qquad (10.12)$$

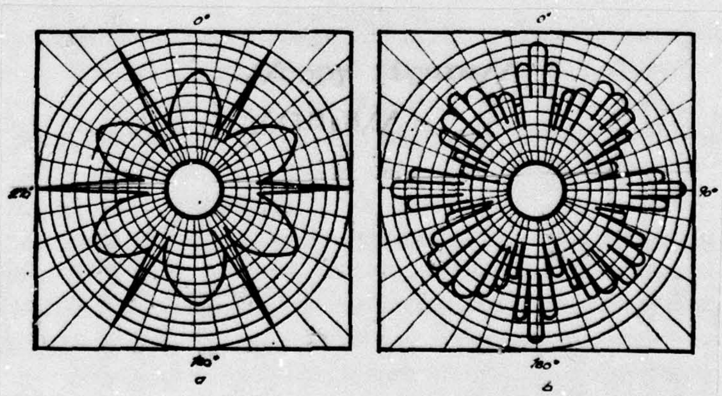


Fig. 10.8. Group eight-cell reflector with triangular sides; cell distribution under angle of 60° with respect to the vertical: a - reflector in the initial position, and b - reflector under the slope of 45° with respect to the vertical.

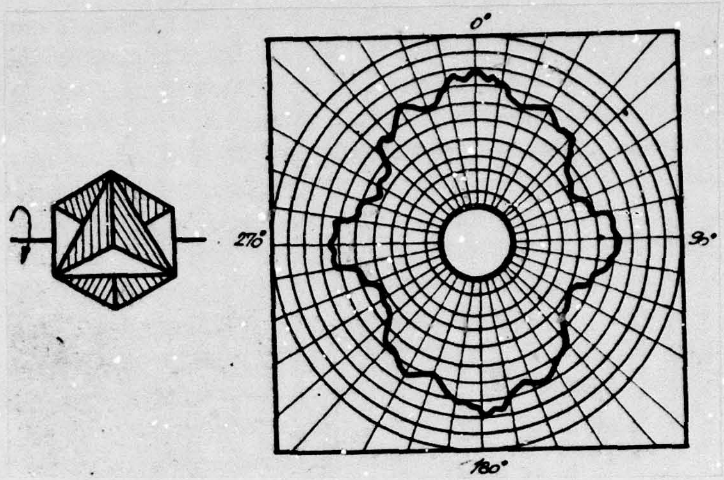


Fig. 10.9. Group rotating eight-cell reflector with triangular sides; distribution of cells is under angle of 60° with respect to the vertical; the reflector is at a slope to 45°.

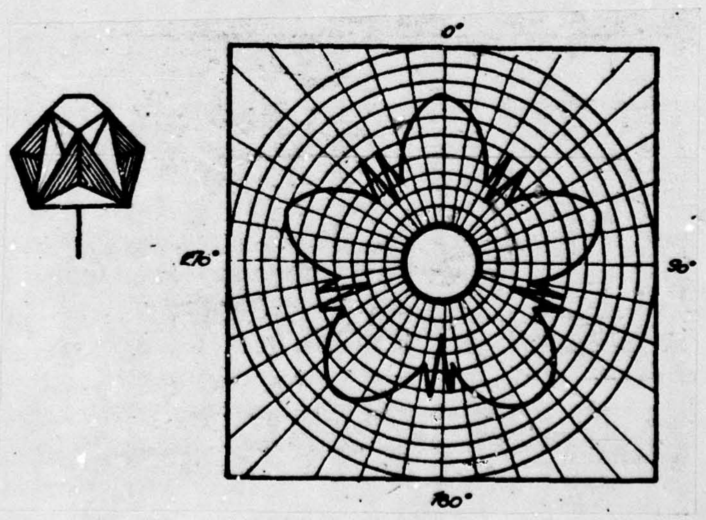


Fig. 10.10. Group five-cell reflector with cells distributed in circle.

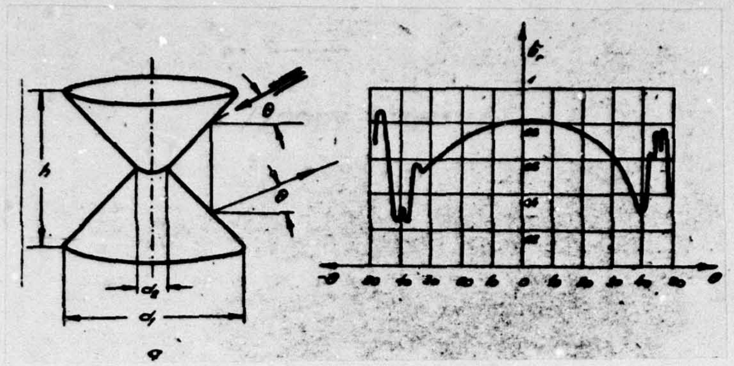


Fig. 10.11. Boconical passive reflector: a - illumination geometry, b - reflection diagram as a function of angle of incidence.

Although this type of passive reflectors has a very favorable reflection diagram, it has not been significantly employed as yet, mainly due to the technological difficulties during their manufacture (large dimensions d_1 and h and the required accuracy in manufacture require the application of costly machines for the operation).

Lunenberg lens as passive reflector

Group and biconical reflectors do not as yet give an ideal reflection diagram in all directions. The most ideal reflector would be a ball, however its reflex surface is small. A good solution to this problem, although technologically complicated and therefore very costly, is Lunenberg lens.

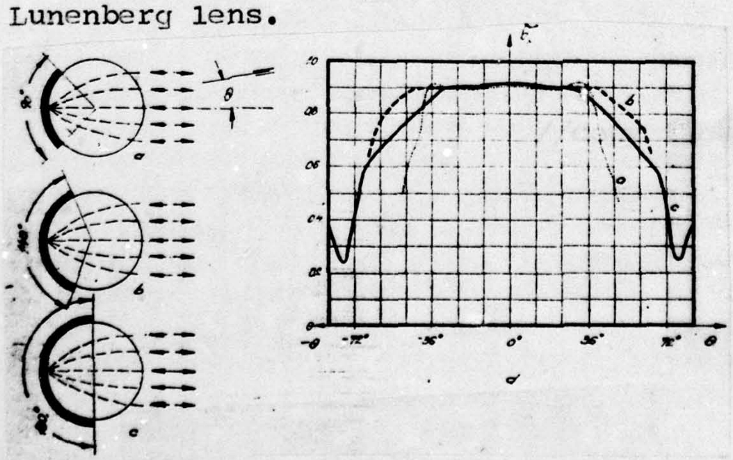


Fig. 10.12. Lunenburg as passive reflector: a - metallized surface under angle 90°, b - metallized surface under angle 140°.

Fig. 10.12 (Cont'd). c - metallized surface under angle 180°, d - reflection diagram for cases under a, b, c, and various angles of incidence θ.

Lunenberg lens is a dielectric ball, where the dielectric constant ε of the extraneous surface (where its approximate dielectric constant is equal to the dielectric constant of air) changes toward the interior. A part of the extraneous surface is metallized. The incoming rays become - due to the variable dielectric constant of the ball - by passing through the ball bent, collected, and focused on the metallized surface, they become reflected from it, and are again bent and leave with the same polsarization in the direction they came from (Fig. 10.12). The refraction coefficient in Lunenberg lens varies according to the law

$$n=\sqrt{2-\left(\frac{r}{r_0}\right)^2} \qquad (10.13)$$

where: n = refraction coefficient

r = current radius

r_o = radius of extraneous surface.

The interrelationship between the dielectric constant and refraction coefficient is given by the relationship

$$\varepsilon=n^2=2-\frac{r}{r_2} \qquad (10.14)$$

The electrical reflex surface amounts to

$$\sigma=\frac{4\pi^3\cdot r_0^4}{\lambda^2}=\frac{\pi^3\cdot d_0^4}{4\lambda^2} \qquad (10.15)$$

where: d_o = radius of the ball.

The more the dielectric constant inside the ball varies according to the law $\varepsilon=n^2=\frac{2r_0}{r}-1$ (10.16).

(10.16)

a ball is obtained in which such refraction of incident rays occurs that they turn around by 180° and return in the direction they came from (Fig. 10.13).

Inasmuch as such a dielectric ball enables equal reflection in any given direction, it does not need a metallized surface. The only problem is in manufacturing technology, inasmuch as in its very center the dielectric constant should be infinite.

In practice, Lunenberg lense is manufactured from a large number of dielectric cores (one in the other), where the dielectric constant

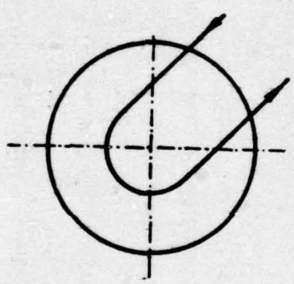


Fig. 10.13.

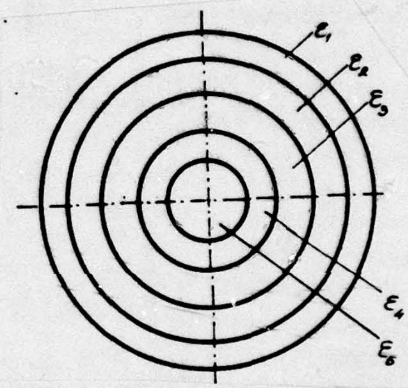


Fig. 10.14. Cut of Lunenberg lens with variable dielectric (principle).

toward the center uniformly increases according to the law of equations 10.14 or 10.16. As material can be used various grades of styropore (Fig. 10.14).

<u>Van Ata passive reflector</u>

Van Ata passive reflector is really a passive antenna lattice made up of several horizontal and vertical rows of dipoles arranged in one plane at a distance of $\frac{\lambda}{4}$ from the even metal surface, namely the reflector. The connection of the dipoles is done by equal pieces of

coaxial cable symmetrically with respect to the center. In Fig. 10.15 is shown the diagonal cross-section and the connective system (dipoles with the same numbers are interconnected).

For Van Ata reflector to be effective for all polarization of the incoming wave, the orientation of individual dipoles in the pair varies from dipole pair to dipole pair. The usual difference in the orientation of two neighboring pairs is 90° and is shown in Fig. 10.16a.

The reflex surface of a Van Ata reflector made up of n semiwave dipoles displaced at a distance of $\lambda/2$ from one another and at a distance of $\lambda/4$ from the reflector amounts to

$$\sigma \approx \frac{1}{4} \cdot \pi \cdot n^2 \cdot \lambda^2 \left[\sin\left(\frac{\pi}{2} \cos \theta \right) \right]^4 \qquad (10.17)$$

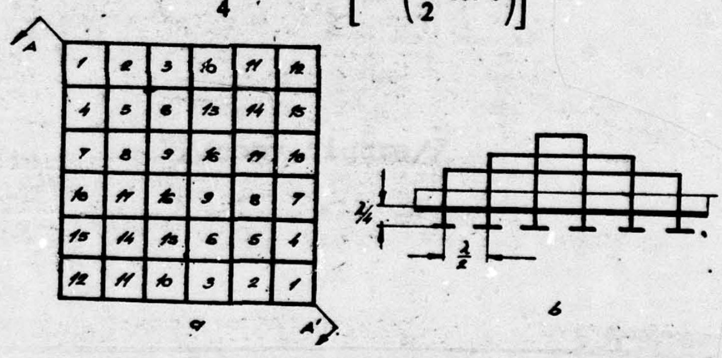


Fig. 10.15. Van Ata passive reflector: a - connective system, b - diagonal cross-section AA'.

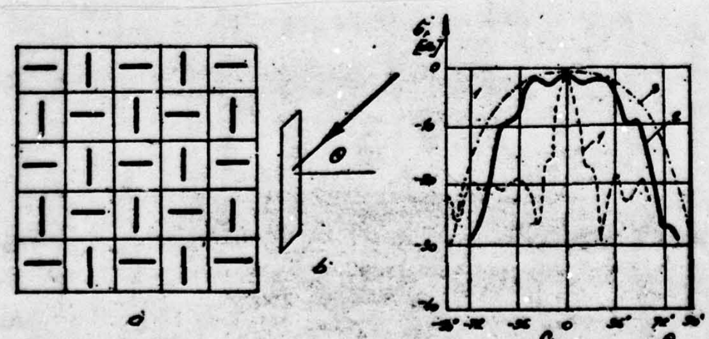


Fig. 10.16. a - diapole angles, b - illumination geometry, c - reflection diagram of Van Ata reflector, 1 - even surface, 2 - experimental value, 3 - theoretical value.

Instead of dipoles one can use spirals, cuts, dielectric antennas, and similar.

The advantages of a Van Ata reflector as opposed to the trilateral angular reflector are:

- reflection diagram has a larger width;

- it can reflect energy in the direction which does not coincide with the direction of illumination;

- by combining dipole orientation one can attain responding on two polarizations of the incoming wave,

- enables installation of amplifier in the joint coaxial cable between the dipoles (Fig. 10.17), whereby a considerable increase in the reflecting signal is attained and thereby an increase in the reflex surface; in this case the passive reflector coverts into an active responder;

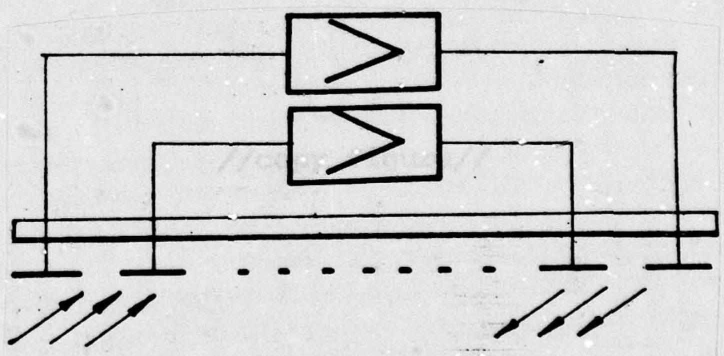


Fig. 10.17. Van Ata reflector as active responder.

- due to the possibility of fabricating in technology printed circuits and band conduits there exist as yet undreamed-of possibilities of application for various false echoes, especially in combination with semiconductor amplifiers in integrated structures technology;

- instead of an amplifier one can also use a modulator whereby the reflected signal can be modulated at will and for the purpose of creating corresponding illusion on the screen of the jammed radar.

10.2. DECREASING RADAR REFLEX SURFACE OF OBJECT UNDER OBSERVATION

One of the most important methods of electronic countermeasures in the fight with radar installations is the decrease of the reflex surface of the object under investigation. In regard to that the distance of uncovering for the same radar installation is directly proportional to the reflex surface of the object

$$R=k\sqrt[4]{\sigma_{obj}}.$$

each decrease also produces a smaller distance of uncovering, which in most of the cases is crucial. The significance of this problem can be obtained from the fact that from 1965 to 1968 there were approximately 39 patents filed in this field in the USA, West Germany, East Germany, Japan, and France.

Basically, the decrease in the radar reflex surface of the object under observation can be obtained two ways:

- by commercial construction of the object under observation and by the selection of such a form that guarantees a minimal reflex surface (see Chapter XI, p. 284 of copy).
- by deposition of various layers or greases on the surfaces which take part in the creation of radar reflex surface, whereby its decrease in the electrical sense is achieved.

There are mainly two kinds of surface layers, the first being of the <u>absorption</u>, and the second of the <u>interference</u> type.

The incoming electromagnetic wave is primarily attenuated during its passage through the layer, it is reflected on the object, and during its return it is again attenuated. This is the result: the reflected energy changes, thereby producing an impression that the reflection

was done on a superficially smaller object.

With the second kind, we have annihilating interference between the incoming and the reflected wave. The result is again the same impression.

With respect to that these layers are deposited on extraneous surfaces of aircraft, vehicles, or objects, they must possess besides electrical also extraordinary mechanical properties. The primary properties of these materials are:

- that they lead to maximal attenuation of electromagnetic waves within a broad frequency region;
- that reflection of electromagnetic waves is minimal from their surface;
- that weights and volumes are minimal;
- that they possess excellent mechanical and thermal properties, and
- that they are simple to construct and apply.

10.2.1. ABSORPTION LAYERS

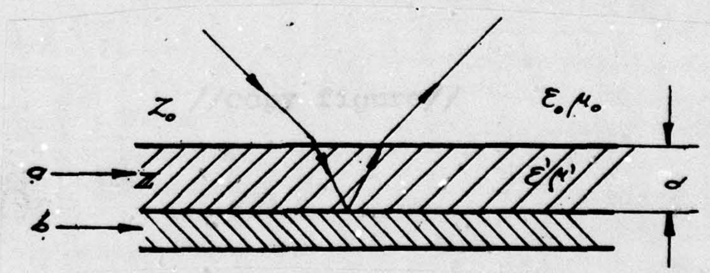


Fig. 10.18. Geometry of absorption layer: a - absorption layer, b - metal surface.

If it is assumed that the absorption layer is infinitely large and ideally even, the reflection coefficient can be written as the ratio of the impedances of the media

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \qquad (10.18)$$

Z_o is the impedance of free space and amounts to

$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi \tag{10.19}$$

Z is the impedance of the attenuated layer and it amounts to

$$Z = \sqrt{\frac{\mu'}{\varepsilon'}} = \sqrt{\frac{\mu \cdot \mu_0}{\varepsilon \cdot \varepsilon_0}} \tag{10.20}$$

If equations 10.19 and 10.20 are substituted in 10.18 one obtains

$$\Gamma = \frac{\sqrt{\frac{\mu}{\varepsilon}} - 1}{\sqrt{\frac{\mu}{\varepsilon}} + 1} \tag{10.21}$$

(where ε and μ are the specific dielectric constant and permeability of the layer material). From relation 10.21 it is clear that there shall be no reflection if $\Gamma = 0$, and that then must be $\mu = \varepsilon$. This means that the absorption material must physically have the characteristic of an insulator with magnetic properties.

If by n we designate the fracture coefficient, and by k the absorption coefficient, then they are related by relationship

$$\sqrt{\varepsilon \cdot \mu} = n + jk \tag{10.22}$$

Using relationship 10.22 one can write relationship 10.21 in the form

$$\Gamma = \frac{n + jk - n}{n + jk + n} \tag{10.23}$$

To approach real conditions we must consider that the material is characterized by complex constants ε' and μ'

$$\left.\begin{aligned} \varepsilon' &= \varepsilon \cdot \varepsilon_0 = \varepsilon'_r + j\varepsilon' k = \varepsilon_0(\varepsilon_r + j\varepsilon_k) \\ \mu' &= \mu\mu_0 = \mu'_r + j\mu'_k = \mu_0(\mu_r + j\mu_k) \end{aligned}\right\} \tag{10.24}$$

(where the imaginary parts of the constant designate losses which occur in the material due to conductivity).

The reflection coefficient is equal to 0 if the condition is fulfilled

$$\mu = n + jk \tag{10.25}$$

When equations 10.24 and 10.25 are compared, additional expressions are obtained for the characteristics of the material. There shall therefore be no reflection if the condition is fulfilled

$$\varepsilon = \mu; \quad n = \frac{\mu_r}{\mu_0}; \quad k = \frac{\mu_a}{\mu_0} \tag{10.26}$$

To the given conditions correspond ferromagnetic materials with high losses. Basically this are materials prepared from a mixture of a weak dielectric and ferromagnetic particles. Generally, multilayer absorbers are prepared, whose first layer must have relative constants μ_r and ε_r as close as possible to μ_0 and ε_0 (air constants) and losses equal to 0. In subsequent layers the increase in ε and μ must be gradual, since abrupt increases lead to increased reflection at the interface between two layers (Fig. 10.19).

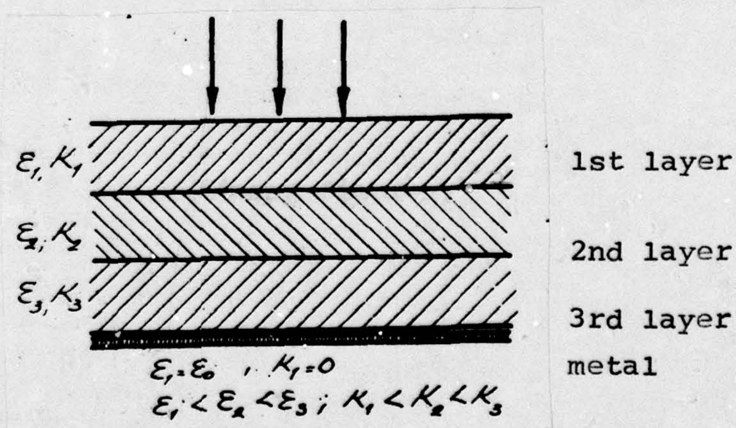


Figure 10.19

Layer distribution of absorption attenuator

10.2.2. INTERFERING LAYERS

In interfering layers the effect of decreasing reflex surface obtains by mutual cancelation of the reflected wave from the air--layer surface and the wave reflected from the layer--metal surface (Fig. 10.20).

The incoming wave (1) is manyfold reflected from boundary surfaces I and II. As the wave passes through the interfering layer, it also becomes attenuated.

No reflection will occur if the sum of all the departing waves in the direction whence they came is equal to zero, which will happen if the following conditions are fulfilled

$$\beta = \ln \frac{1}{\Gamma} \tag{10.27}$$

$$d = (2 \cdot n + 1) \cdot \frac{\lambda \varepsilon' \mu'}{4} \tag{10.28}$$

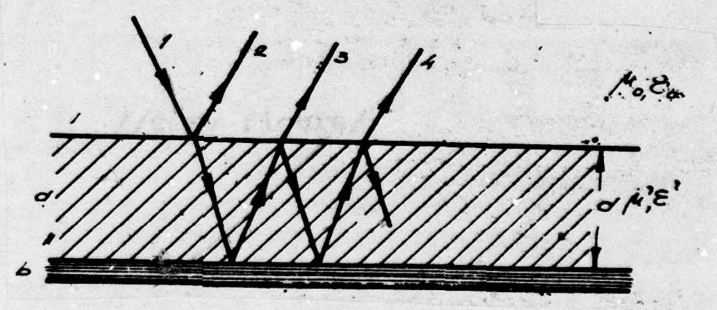


Fig. 10.20. Geometry of interfering layer; a - interfering layer, b - metal surface.

where: β = attenuation in layer per single passage of wave,

d = thickness of the interfereing layer,

$\lambda_{\varepsilon' \mu'}$ = wavelength in the layer,

n = 0, 1, 2, 3.

Due to the smaller amount of ferromagnetics of their composition the interfering layers are easier to employ, however due to their

higher thickness and strong dependence on the wavelength they are not suitable for such use. For this reason they are by themselves rarely used, and when they are used they are combined with absorption layers.

10.2.3. COMBINED LAYERS

Due to the shortcomings which both the interfering and the absorption layers individually possess, they are most often used in combination.

The outside surface of the combination is in most cases prepared in the form of small pyramids, which provide - depending on their angle - multiple (manifold) reflection and hence multiple weakening (Fig. 10.21).

The layers are combined in such a way that an absorption layer follows an interfering layer (Fig. 10.22). Depending on the type of materials

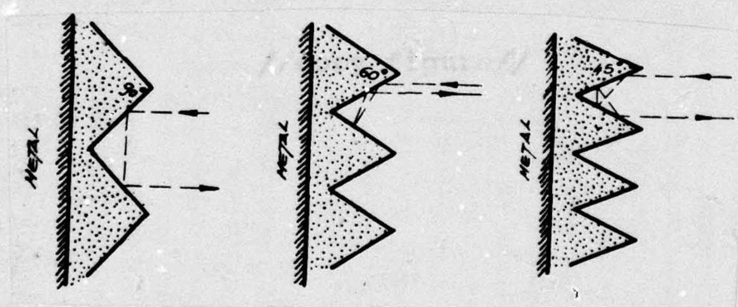


Fig. 10.21. Effect of angle at top of the pyramid on the number of reflections.

used and the number of layers, attenuating coatings with greater or lesser attenuation and greater or lesser frequency dependency are obtained.

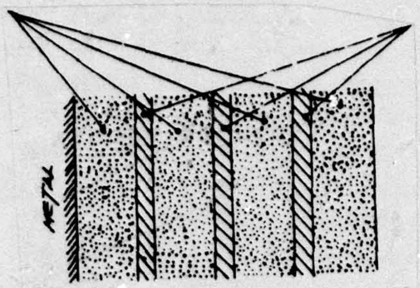


Fig. 10.22. Combination attenuating material (cut).

The entire technology and materials for the decrease of the radar reflex surface are effective only if the linear dimensions of the object which is protected (screened) thereby are much higher than the wavelength inside the layer, which means when the following condition is fulfilled

$$\frac{2\pi}{\lambda_{\varepsilon'\mu'}} \cdot \sqrt{S} > 10 \tag{10.29}$$

where: S = surface of object covered by layer for decreasing of reflex surface in [m],

$\lambda_{\varepsilon'\mu'}$ = wavelength in the layer expressed in m .

The wide-bandedness by frequency is obtained with attenuating material whose surface is divided into segments, each of which has its own resonance frequency. Thus, for instance, the firm "Eltro G.m.b.H. Gesellschaft fuer Strahlungstechnik" //Eltro Company for Radiation Technology, Ltd// from West Germany patented (West German Patent No. 977516 kl 21 a^4 48/63 G01S, $H01_2$ dated 3 Nov 1966) attenuating material of this type. The dimensions of the segments are from $\lambda/2$ to 5λ, where λ is the mean wavelength of the frequency domain (Fig. 10.23

Generally the length d of the segments is always the same, suitable for fabrication and application. The spacing between the segments e is

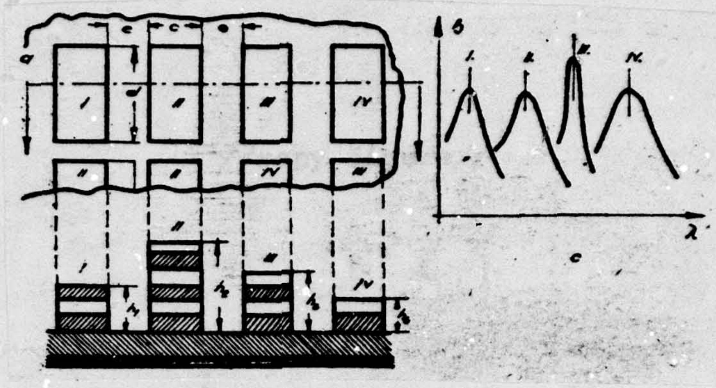


Fig. 10.23. Attenuating material with rectangular segments: a - view from above, b - cross-sectional cut, c - attenuation diagram (β - attenuation, λ - wavelength).

always the same, generally from 0.5 to 10λ . The frequency dependence of the segment is determined by its height h, through the expression

$$h=\frac{(2n-1)\lambda}{4\sqrt{\varepsilon'\mu'}}$$

and this in such a way that the construction is performed either from the same material (same ε' and μ') with different heights h for the various wavelengths or, well, with the same heights h but for different wavelengths with different properties of the materials. A favorable combination results in desired attenuation, as shown in Fig. 10.23c.

Experiments with attenuating materials distributed on the belt (band) 271
showed a great dependence of their effectiveness on polarization of the incoming wave. Great difficulties were encountered in case of circularly or elliptically polarized incoming wave. For this reason, materials with segments of a circular shape are being built (Fig. 10.24).

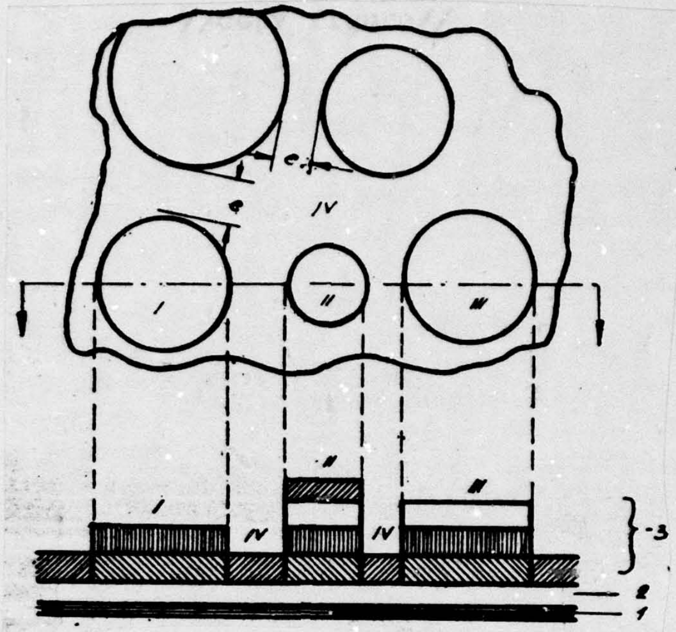


Fig. 10.24. Attenuating material with circular segments: 1 - metal reflex layer, 2 - interference layer, 3 - attenuating layers of various properties.

These segments generally have various diameters, but are positioned at equal spacings e. The resonance frequency of the interlayer IV is selected either in the middle or at the ends of the frequency domain of the application.

On Fig. 10.25 is shown a wide-band attenuator of segmental design and the same thickness. Two groups of segments 1 and 2 are employed which attenuate each at their frequency λ_1 and λ_2 (Fig. 10.25c). The length of the segments is $5\lambda_1$ and $2.5\lambda_2$, and the width is $\frac{1}{2}\lambda_1$ and $\frac{1}{2}\lambda_2$. Mutual distance between two rows of segments is $\frac{1}{3}\lambda_1 - \frac{1}{6}\lambda_2$.

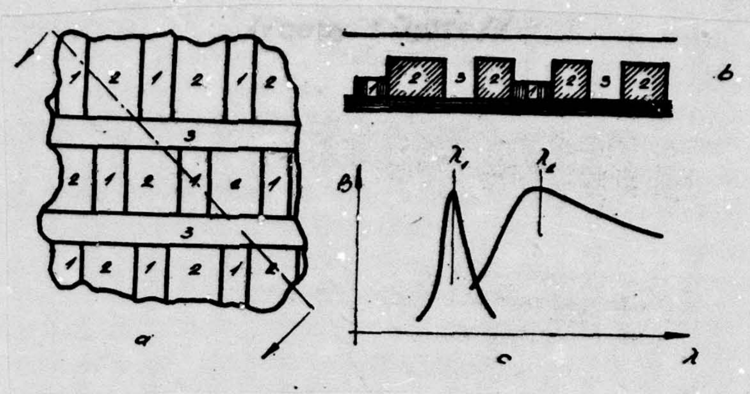


Fig. 10.25. Segmental attenuating material of equal thickness; a - arrangement of the segments, b - cross-sectional cut, 1 - attenuating segment for λ_1, 2 - attenuating segment for λ_2, 3 - adaptable layer and filler layer, 4 - metallized reflex layer, c - attenuation diagram.

The attenuated segments (1 and 2) are placed in prearranged order on reflex layer (4), which is made up, for instance, of plastics containing a high percentage of aluminum dust as filler. Layer 3 fills in the gaps between the attenuating segments and adjusts the entire construction to free space impedance (ε of the layer to be as small as possible). The segments may have various shapes (circle, rhmobus, ellipse, rhomboid, etc.), depending on the wide-bandedness, polarization effect, and the attaining of maximum attenuation.

An effective combination layer and very simple to construct is the one patented by German patent No. 977527 kl. $21a^4$ 48-63 G01s H01q dated 24 Nov 1966. It is applicable for frequency rage 5000 to 2000 MHz. It can be prepared very simply, by mixing, and it is applied by brush or pistol for spraying on metal surface whose reflex surface is to be reduced. The total thickness of the layer is 3 to 5 mm. The preparation

is given in quantities sufficient for 1 m^2. The layers are applied in the following order to the metal surface:

first layer - 110-180 g of mixture isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane in the ratio 9:1;

second layer: in 700-900 g mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethan in the ratio 9:1 is mixed 20-40% inorganic filler, preferably $MgCO_3$ in the form of flour;

third layer: in 110-180 g of mixture of isocyanate, adipinic acid polyester, glycerin, and butyleneglycol with polyurethane in the ratio 9:1 is mixed 5% fine-grained soot;

fourth layer: in 2000 to 3000 g mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane in the ratio 9:1 is mixed 50-80% high-frequency iron with average grain size 5 to 10 microns. The mass is applied in 5 partial layers. While the layers are still plastic, using positive and negative matrices, pyramidal, conical, cylindrical, semicircular, and similar shapes are impressed into the surface. The size of these forms and their spacings must correspond to the wavelength used;

fifth layer: in 350-550 g mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane in the ratio 9:1 is mixed: in 2/3 mixture 20-40% $MgCO_3$ filler, and in 1/3 mixture 1-5% soot;

sixth layer: in 450-650 g mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane in the ratio 9:1 is mixed 50-80% high-frequency iron with grain size less than 3 microns;

seventh layer: in 80-120 g of mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane in the ratio 9:1 is mixed: in 2/3 mixture 20-40% $MgCO_3$ filler, and in 1/3 mixture 1-5% fine-grained soot;

eighth layer: 80 to 120 g mixture of isocyanate, adipinic acid polyester, glycerine, and butyleneglycol with polyurethane or silicones in the ratio 9:1.

The given ratios are understood to be average values. Depending on the hardness, other ratios can also be employed. Limiting values are 9.5:0.5 and 7:3. Instead of soot one can use graphite or semiconductor materials in powder form such as ZnO, BeO, Ge, or powder metals such as aluminum or its alloys.

Fot simplification's sake, the second layer can be reduced by half, and the third and fourth layers can be left out. In this case the attenuation is reduced by one-half of the starting value.

If one wishes to expand the frequency range and increase attenuation, a metal-coated (metallized) or graphitecoated (impregnated) plastic foil must be inserted between the fifth and the sixth and between the sixth and the seventh layers.

The attenuating masking screen can be done in the following way:

- First layer: foil 0.01 to 5 mm in thickness (recommended 1.2-2.0 mm thickness) made of polyisobutylene. Care must be taken that losses do not exceed $t\delta$ = 0.1, which is accomplished by the use of such fillers that the total dielectric and magnetic losses attain this value;

- second layer: foil 0.01-5 mm in thickness (recommended is 2 mm), rolled and vulcanized, with the following composition: - 500-700 parts

polyvinyl chloride; - 250-350 parts mixture of toluene, isobutyl, and toluoletylsulfonamide; - 700-900 parts of high-frequency iron 5-10 micron in grain size; - 80-120 parts of polymerized product of butadiene, 1 part paraffin 42°C, 6-4 parts zinc ehitener, and 1 part sulfur;

- third layer: foil 0.01-5 mm in thickness (recommended 0.4-0.6 mm) made of polisobutylene with 1-5% soot. Instead of soot one can also use zinc oxide (ZnO), beryllium oxide (BeO), germanium (Ge), or aluminum (Al) in powder form;

- fourth layer: foil 0.01-5 mm in thickness (recommended 1.7-2.5 mm) made of polymer of butadiene and acrylic acid nitrite with 50-80% high-frequency iron with grain size 0.1 to 2 microns;

- fifth layer: finishing (terminal) layer 0.01-5 mm in thickness (recommended 0.4-1.2 mm) made of polyisobutylene with 2-5% ZnO.

The thus prepared layers are wetted to one another under pressure and using a suitable adhesive.

The resulting material has effective attenuation in the frequency range from 10,000 to 4,000 MHz. To decrease the weight of the masking screen, one can by punching or stamping cut out apertures of various shapes and being $\frac{\lambda}{5}$ to $\frac{\lambda}{10}$ in size (where λ is the average wavelength in cm for the attenuating frequency region). For the region from 1 to 10 cm, these apertures measure 2 mm to 2 cm in size. One must be careful here that one does not cut out more than 40% of the total surface area.

The attenuating material with specific resistivity approximately $7 \cdot 10^3$ ohm/cm^2, which can be applied by brush, spray pistol, in one or more thin layers $7\text{-}8 \cdot 10^{-2}$ mm in thickness and which absorbs more

than 68% of the incoming energy at a frequency of 10,000 MHz can be made in the following way.

As binders serve various kinds of waxes, epoxy resins, or similar materials.

As fillers are the most suitable manganese oxide (MnO) and ferrous oxide (Fe_2O_3). They can be replaced by aluminum oxides, as well as by oxides of zinc, tin, barium, or strontium, only with these the attenuation effects are somewhat weaker.

The filler is prepared using the procedure outlined in Table 10.3. Crushing is done in a steel mill to pellets, and the filler thus prepared is mixed with the binder material (waxes, epoxy resins, and similar) and is applied by brush or paint spray pistol on the basis of which the reflex surface is to be decreased.

10.3. CHANGE IN THE SHAPE OF THE RADAR REFLEX SURFACE

The first application of the method using the change in the radar reflex surface dates back to the World War II years. The measures which Germans used to change the shape of ground reflex surface have in many ways decreased the effectiveness of Allied bombing raids. Thus they have, for instance, so masked a part of Hamburg port that on radar screens it looked as a part of the city proper and that the imitated port was situated on open sea (Fig. 10.26).

It has already been said in chapter on World War II that Allied navigational systems did not reach to Berlin. In order to bomb it, however, they made use of radars and especially salient objects on the ground as orientation points. For Berlin these were lakes of a specific shape, such as abound in its surroundings. Using floating bilateral passive reflector, to which the water surface served as the

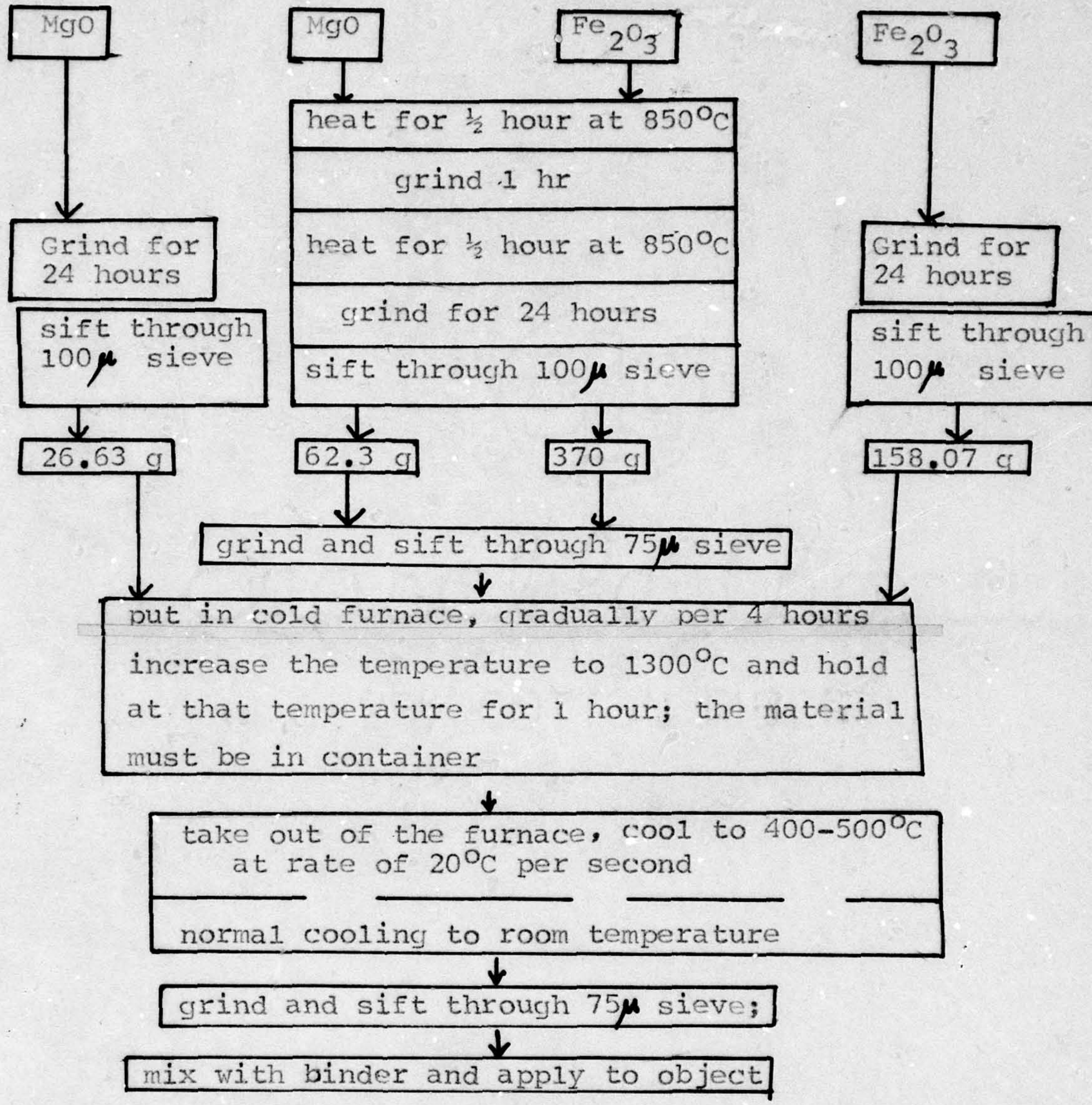


Table 10.3. Technological procedure for preparation of filler (U.S. patent No. 3,185,986).

Fig. 10.26. Radar pattern of Hamburg port from 1943; a - unmasked port, b - masked port.

third side, Germans successfully solved this problem (Fig. 10.27). The reflectors were positioned at intervals which corresponded to the probable width of the beam $\Delta\beta$ of Allied airplane radars.

The contemporary development of radar installations at centimeter and millimeter wave region, its increased sensitivity and resolution capability, enhanced interpretive capacity of pictures obtained, these all led to that radar installations are being used more and more as a means to reconnoiter terrain under all meteorological conditions and under all visibility conditions (in lieu of airplane reconnaissance) with instantaneous transfer of the picture to the ground. Thus they are used as a means for aiming and bombing ground objects. The resolution capability has greatly increased, so much so that for a radar for lateral observation we have a resolution of 7.5 m from an altitude of 2,500 m. (According to data from 1968 for an F-111 airplane with a radar for lateral observation mounted on it with resolution capability which almost corresponds to optical photograph). This type of radar is capable of revealing vehicle columns, individual vehicles, groups of people, and all objects which are speeding ahead

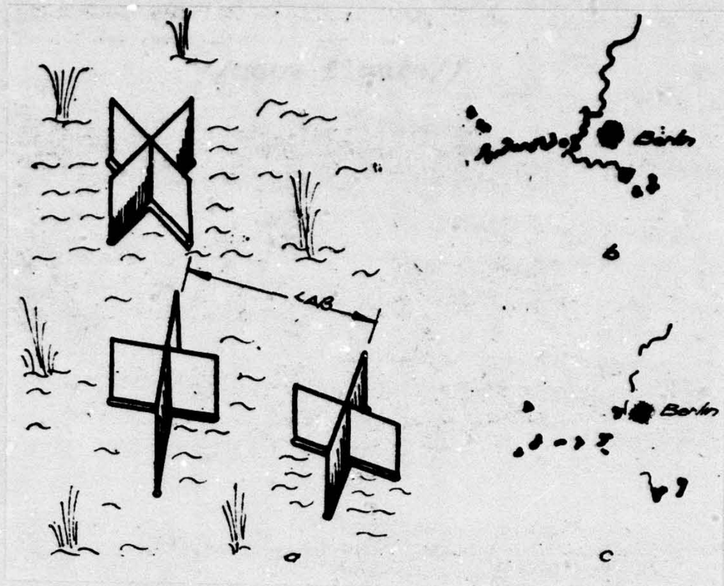


Fig. 10.27. Change in the shape of reflex surface of lakes in the surroundings of Berlin in World War II: a - floating passive trilateral reflectors, b - view of the lakes on radar display prior to masking, c - view of the lakes on radar display after masking.

individually, and similar, and night is no longer a mantle which can be used to conceal all movements and concentrations of units.

On the other hand, the appearance of the large number of radars for detection of movements of life forces and vehicles at small distance has therefore also resulted in the approchement of enemy camps, lines, or fortifications associated with radar detection.

For this reason, the modern procedures of optical masking of the terrain, objects on it, mobile objects, and troops, must be perfected by masking which would make them radar-"invisible."

Terrain and objects. - In radar sense all those objects are salient where the difference in the magnitude of the specific reflex surface is very pronounced. Such objects are lakes, rivers, bridges, roads, runways, railway tracks, individual vegetation complexes, larger edifices, all lone objects, factory warehouses, and similar (see chapter XI, p. 284 of copy) All such objects can serve as navigation aids, for whatever reasons, or as objects of attack. For this reason, all radar-salient objects must not only benefit from the simultaneous use of measures to decrease or increase the effective radar reflex surface, but must also be made one with the surroundings, or in some way their location must be changed. Thus, for instance, by use of absorption layers one can decrease the reflex surface of a bridge, and at some other area one can simulate a bridge by use of several passive reflectors; or using a suitable combination of absorption layers and passive reflectors, a certain lone factory complex can be equalized with the surroundings. Using a suitable arrangement of passive reflectors along a river, airport, highway, or railroad, they can be redirected or even "erased."

War technology. - Vehicles (tractors, caterpillars), artillery equipment of all kinds and calibers, mobile radio stations, transport wrapping material and containers for missiles, engines, or auxiliary parts, ships of all tonnages, aircraft of all kinds, and similar, represent in the radar sense reflection objects with pronounced radar reflex surface. Thus in the design of war technological equipment one must take this into consideration, and hence great care and attention must also be devoted to its masking against radar detection.

The essence of masking does not consist in that the radar reflex surface of these objects is completely decreased, but rather in

"drowning" these objects in their surroundings. On the contrary, they will be visible, whether they are raised on the radar screen above the illumination of the surroundings or that they are below the illumination of the surroundings (dark fields on light background). By comprehensive investigations on the part of experts, masking techniques have been developed which can easily be applied.

War technology in the field is generally concealed by covers to decrease the reflection. Thus, for instance, the American firm "North American Aviation" built and patented (U.S. patent No. 3,349,396 kl. 343-18 dated 24 October 1967) a model construction cover for the

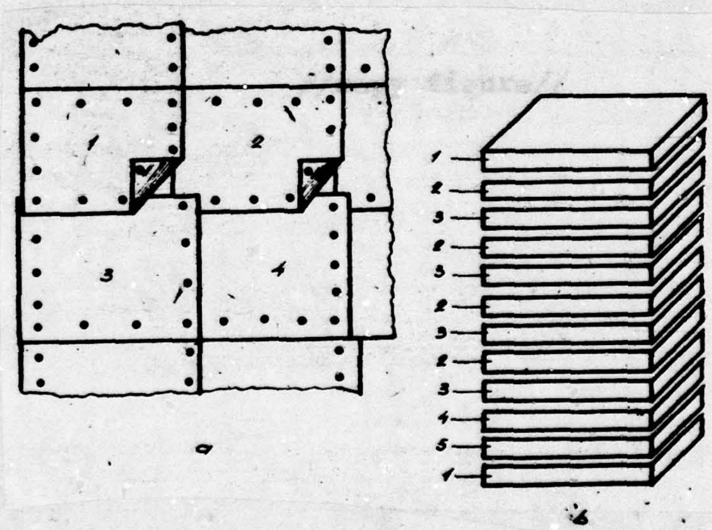


Fig. 10.28. Modular masking cover; a - exterior view of component modules, b - cut of the module, 1 - exterior flexible layer - textile fabric, 2 - absorption layer, 3 - interference distance layer, 4 - thin metal layer, 5 - protective layer made of plastic.

protection from radar infrared reconnaissance. The cover is an interference absorber, in which the absorption layers are separated by

interference distance layers (Fig. 10.28). Modular construction makes it possible to provide mutual combination of modules in such a way and with such properties that coincidence of reflex properties of the cover and the same properties of the surroundings can ensue, as well as quick replacement in case of damage.

The cover enables the decrease in reflection by more than 20 db in the range of 2 to 20 GHz. It has a thickness of 22.2 mm and specific weight 0.065 kg/dm^3.

Open warehouses with boxes, barrels, containers, and similar can very easily be detected by radars at wavelength 0.8 to 10 cm. Masking of such warehouses is absolutely essential. Tests have shown that with decrease in the reflected signal by 20-30 db, the "sinking" of such objects into the surroungings can be achieved. On the basis of this, the firm "Eltro G.m.b.H. und Gesellschaft fuer Strahlungs-technik" (Eltro Radiation Technology Company, Ltd) from West Germany developed and patented (West German patent No. 977,522 kl. $21a^4$ 48/63, H01q G01s, dated 3 November 1966) a procedure for masking boxes or containers. The protective (screening) material is applied from the interior side of the wrapping material. For the production of the

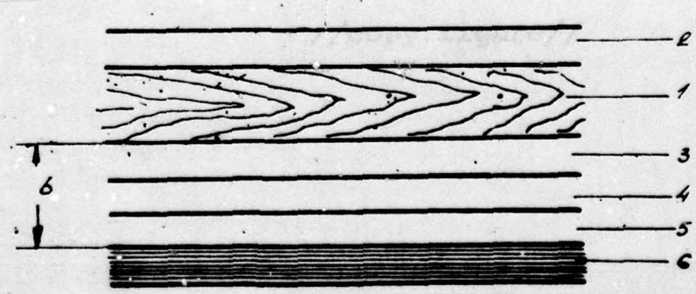


Fig. 10.29. Sectional view of protective layer of warpping material: 1 - wrapping layer, 2 - water-resistant layer with optical and ir-masking, 3 - absorption layer, 4 - distance layer, 5 - interference layer, 6 - reflex layer - metal-coated surface.

container is selected a material which has the characteristic impedance somewhere between the free space and the boundary layer of the protective material. For this purpose, some sort of fibrous material can be used, as well as wood, carton, polyester, and similar. On the external surface of the container one can apply a layer for the protection against moisture together with the layer for optical or ir-masking. The interference attenuating material has a layerlike structure (Fig. 10.29). The last layer is metal reflecting, for the purpose of retaining always the same reflection conditions.

The thickness of the entire packet b is given by the expression

$$b=(2n-1)\frac{\lambda}{4}\sqrt{\varepsilon\cdot\mu}$$

where: n = whole number

λ = wavelength of incoming waves

ε and μ = dielectric constant and permeability of the material used

For masking or artillery positions this firm developed a lubricant which is applied in this layer on the conventional masking screen. The absorption deposit is of resonance type with increased permeability. The thickness of the layer is smaller than $\lambda/7$ and it is determined by the expression where the symbols are the same as in the preceding expression).

$$b=\frac{(2n-1)\lambda}{4\sqrt{\varepsilon_r\cdot\mu_r}}$$

Troops. - Due to the application of light portable radars, the troops with their weapons have also become the target of radar observation. The average radar reflex surface of a man 180 cm in height and weighing approximately 75 kg is approximately 0.8 m^2.

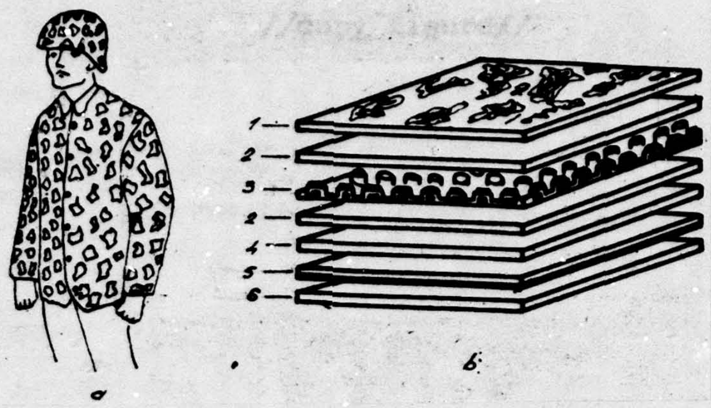


Fig. 10.30. Protective material for troops; b) Cross-sectional view: 1 - water-resistant fabric with optical masking, 2 - absorber, 3 - distancer, 4 - interference layer, 5 - metallized surface, 6 - internal fabric made of cellulose fibers.

If one adds to this the helmet which is required under war conditions, which - if in first approximation we replace it by a ball 0.25 m in diameter - has a reflex surface $\sigma = 0.237\ m^2$, the total surface then is already approximately 1 m^2, which even less sensitive radars do not have much trouble in detecting. Added to this surface is also personal weaponry, which due to the smooth metal surfaces of regular shapes (see: 11.1.5, p. 295 of copy) will make a considerable contribution to the overall reflex surface. The firm " North American Aviation" developed and patented (U.S. patent No. 3,349,397 Kl. 343-8, dated 24 Oct 1967) a protective mantle for man and a cover for the helmet. Figure 10.30 shows their cross-sectional view. (Translator's note: PVO = Protiv Vazdušna Odbrana = Anti Air Defense = Air Raid Defense).

Aircraft and missiles. -High speeds and altitudes and the requirements for increased resources and reliability have been behind the needed development of attenuating materials capable at small weights to undergo high mechanical and thermal stresses. Developed have been absorption materials of the ceramic-ferritic type which, although very fine, have good attenuating properties. Special technologies have been developed for adhesion by highly refractory adhesives, and honeycombed beehive constructions have been implemented. This led to that that covering has been abolished in favor of honeycombed constructions which have become ther principal covering for aircraft. The thickness of such a layer is approximately 6 mm, and yet it provides a weakening of by 10 to 20 db in the frequency region from 0.8 to 10 cm.

XI GEOMETRICAL SHAPE IN THE DESIGN OF THE OBJECT UNDER OBSERVATION AND ITS EFFECT ON RADAR COUNTERMEASURES

From the preceding chapters it was seen that the radar reflex surface of an object plays an important role in the detection of the target and that the range of a radar installation is proportional to the radar reflex surface of this target. This dependence is given by expression

$$R = K \sqrt[2]{\sigma} \tag{11.1}$$

where: R = range of radar installation, K = radar installation constant (see equation 8.17), σ = radar reflex surface of the target.

Since radar reflex surface of the object under observation directly depends on its geometrical forms and the angle under which it is being observed, it is necessary - from the point of view of radar countermeasures - that their shape be strictly taken into account for such objects which may in their prolonged use be the object of radar observation. With respect to that radars are used for all kinds of observations, the objects of such observation are no longer just airplanes, rockets, or ships, but rather also different kinds of vehicles (tractors or caterpillars), warehouses, containers, factories, bridges, and similar. From the point of view of radar countermeasures

it is expedient already during the design and construction of the installation to select such a combination of geometrical shapes for its surface so as to give:

- minimal radar reflex surface for targets which must be detected as tardy as possible (airplanes, ships, and similar);

- average radar reflex surface for targets which must "drown" in the surroundings (warehouses, factories, bridges, vehicles, and similar), and

- increased radar reflex surface for targets the early detection of which is very much desiarble (false echoes, various mummies, and similar).

Effective radar reflex surface of an object can be found by calculations for simpler forms, whereas for complicated forms it is obtained experimentally, by measurement on a model, or on the object itself.

11.1 ANALYTICAL METHOD FOR FINDING RADAR REFLEX SURFACE

Radar reflex surface of an arbitrary object can be expressed by the ratio between the field strength of the reflected and the incoming wave

$$\sigma = 4\pi R^2 \left|\frac{E_2}{E_1}\right|^2 = 4\pi R^2 \left|\frac{H_2}{H_1}\right|^2 \qquad (11.2)$$

where: R = distance, E_2, H_2 = reflected electrical or magnetic field; E_1,H_1 = incoming electrical or magnetic field.

Let us assume that the reflex surface S is composed of elementary particles dS. Each such particle is considered to be a source for a spherical field. By summation of all these individual sources, we obtain

$$E_2 = \frac{1}{\lambda}\int_S \frac{E_1}{R} \cdot e^{-j\frac{4\pi}{\lambda}R} \cdot \cos\vartheta \, dS \qquad (11.3)$$

where: dS = elementary surface of surface S (Fig. 11.1),

θ = angle of incidence of radar ray on surface dS,

R = R_0 + r = the distance between the antenna and the elementary surface dS.

In most of the practical cases E_1 and R in the area near the target have a constant magnitude, and hence one obtains

$$E_2 \approx \frac{E_1}{\lambda R} \cdot e^{-j\frac{4\pi}{\lambda}R_0} \cdot \int_S e^{-j\frac{4\pi}{\lambda}r} \cdot \cos\theta \, dS \quad (11.4).$$

Since

$$e^{-j\frac{4\pi}{\lambda}R_0} = 1,$$

then

$$\left|\frac{E_2}{E_1}\right| = \frac{1}{\lambda R} \int_S e^{-j\frac{4\pi}{\lambda}r} \cdot \cos\theta \, dS \quad (11.5)$$

and the equation for obtaining the radar reflex surface is

$$\sigma = 4\pi R^2 \left|\frac{E_2}{E_1}\right|^2 = \frac{4\pi}{\lambda^2} \left(\int_S e^{j-\frac{4\pi}{\lambda}r} \cdot \cos\theta \, dS \right)^2 \quad (11.6)$$

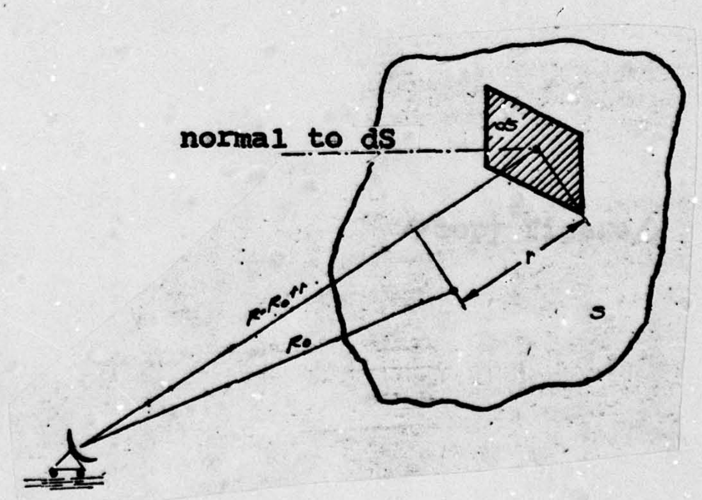


Fig. 11.1. Determination of δ for curved surface.

11.1.1 EVEN METAL SURFACE

If the metal surface is perpendicular to the incoming radar beam but is in size very much larger than λ, then equation (11.6) assumes the form

$$\sigma = \frac{4\pi}{\lambda^2}\left(\int_S e^{-j\frac{4\pi}{\lambda}r} \cdot \cos\theta \, dS\right)^2 = \frac{4\pi S^2}{\lambda^2} \tag{11.7}$$

due to the fact that due to the perpendicular fall $\cos\Theta = 1$, and due to the even surface $r = 0$.

From equation (11.7) it can be seen that the radar reflex surface is the largest when it is illuminated under right angle. Thus, for instance, for a plane with $S = 1\ m^2$, illuminated by radar with $\lambda = 10$ cm, radar reflex surface as follows is obtained

$$\sigma = \frac{4\pi S^2}{\lambda^2} = \frac{4 \cdot \pi \cdot 1}{(0,1)^2} = 1256\ m$$

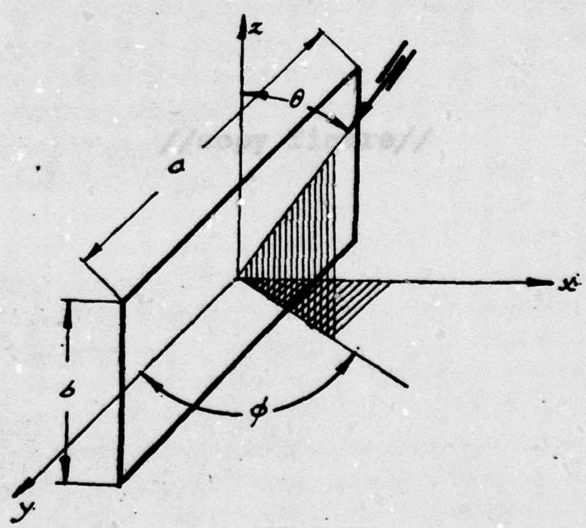


Fig. 11.2. Illumination geometry of an even surface.

If the metal surface of finite dimensions (which is most frequently the case with small objects) is illuminated under an angle, then -

according to illumination geometry from Fig. 11.2 - the reflex surface is a <u>rectangle</u> or a <u>square</u>:

$$\sigma=\left[\frac{k\cdot a\cdot b}{\sqrt{\pi}}\cdot\sin\theta\cdot\frac{\sin(k\cdot a\cdot\sin\theta\cos\Phi)}{ka\cdot\sin\theta\cos\Phi}\right]^2\left[\frac{\sin(k\cdot b\cdot\cos\theta)}{k\cdot b\cos\theta}\right]^2 \qquad (11.8),$$

where

$$k=\frac{2\pi}{\lambda}$$

In the case when $\Phi=\frac{\pi}{2}$, i.e. when illumination is done in the plane normal to the surface and parallel to side <u>b</u>, the reflex surface is:

$$\sigma=\frac{4\cdot\pi\cdot a^2\cdot b^2}{\lambda^2}\left[\frac{\sin(ka\sin\theta)}{ka\sin\theta}\right]^2 \qquad (11.9)$$

<u>Rhombus and rhomboidal surface</u>

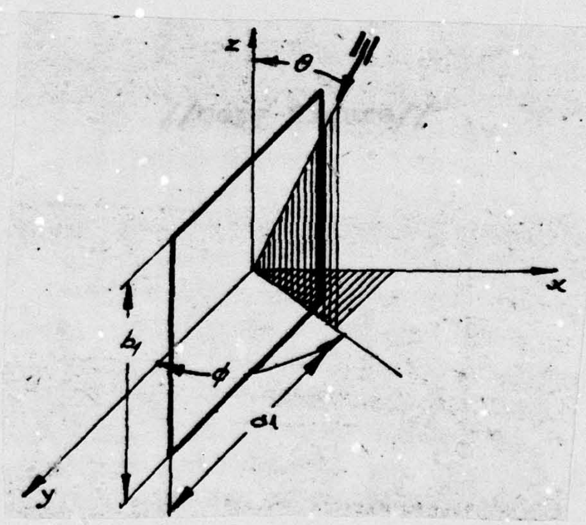


Fig. 11.3. Illumination geometry for a rhomboid.

For rhombus $a_1 = b_1$

$$\sigma=\left[\frac{2\cdot k\cdot a_1\cdot b_1\cdot\sin k(b_1\cdot\sin\theta\cos\Phi+a_1\cos\theta)}{\sqrt{\pi}\cdot k\cdot(b_1\sin\theta\cos\cdot\Phi+a_1\cos\theta}\right]^2\times$$
$$\times\left[\frac{\sin k(b_1\sin\theta\cos\Phi-a_1\cos\theta)}{k(b_1\cdot\sin\theta\cos\Phi-a_1\cos\theta)}\right]^2 \qquad (11.10)$$

where

$$k=\frac{2\pi}{\lambda}$$

Elliptical and circular surface

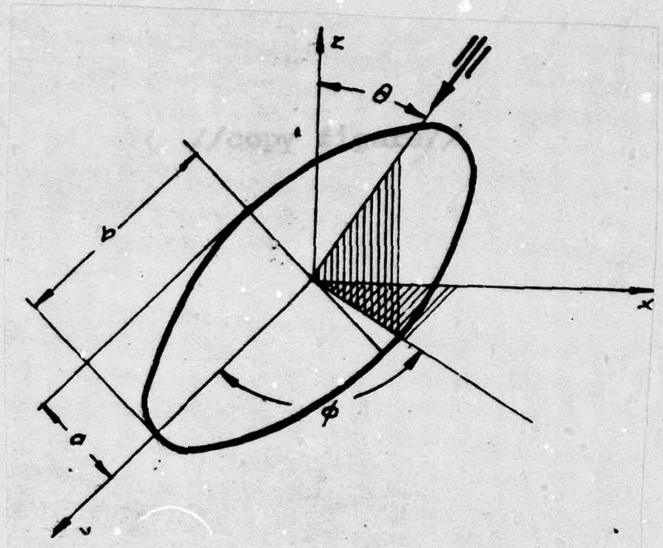


Figure 11.4.

Illumination geometry of elliptical and circular surface.

For elliptical surface

$$\sigma=k^2\cdot a^2\cdot b^2\cdot\left[\frac{J_1(2k\cdot\sqrt{\cos^2\theta\cdot a^2+\sin^2\theta\cos^2\Phi\cdot b^2})}{k\cdot\sqrt{\cos^2\theta\, a^2+\sin^2\theta\cos\Phi\, b^2}}\right]^2 \qquad (11.11)$$

where: $J_1(x)$ is the Bessel function of the Ist order

$$k=\frac{2\pi}{\lambda}$$

For circular surface we have, with respect to Fig. 11.4, $a_1 = b_1 = r$, with Φ always equal to 90°, since all the directions of illumination under the same θ are identical. One obtains:

$$\sigma=\frac{\pi\cdot r^4}{tg^2\theta}\left[J_1\cdot\left(\frac{4\pi r\cdot\sin\theta}{\lambda}\right)\right]^2 \qquad (11.12)$$

at $\theta = 90°$ one obtains the known form

$$\sigma = \frac{4\pi^3 r^4}{\lambda^2} = 4\pi \frac{S^2}{\lambda^2} \qquad (11.13)$$

where $S = \pi r^2$

11.1.2. ELLIPSOID AND SPHERE

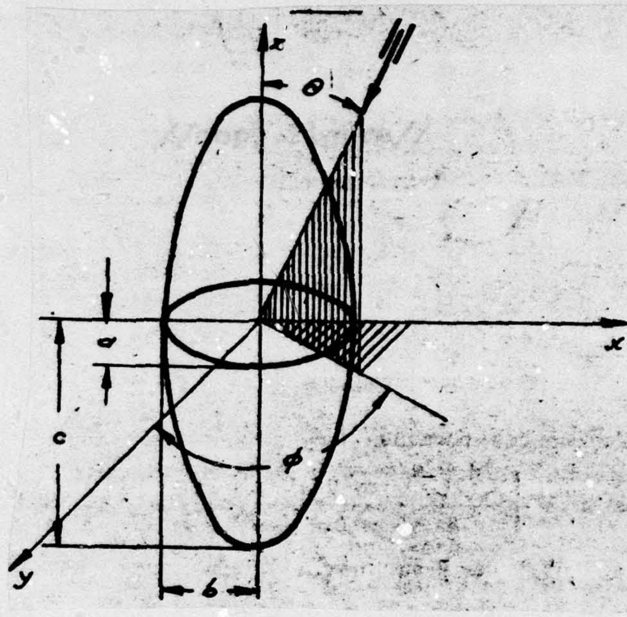


Figure 11.5.

Illumination geometry of an ellipsoid.

For an <u>ellipsoid</u> the reflex surface

$$\sigma = \frac{\pi \cdot a^2 \cdot b^2 \cdot c^2}{(a^2 \sin^2\theta \cos^2\Phi + b^2 \sin^2\theta \sin^2\Phi + c^2 \mathrm{sos}^2\theta)^2} \qquad (11.14)$$

For an ellipsoid where $a = b$, the reflex surface is

$$\sigma = \frac{\pi \cdot a^4 \cdot c^2}{a^2 \sin^2\theta + c^2 \cos^2\theta)} \qquad (11.15)$$

(This shape is used to replace the nose conical surfaces of airplanes).

For a sphere where $a = b = c = r$, the reflex surface is:

$$\text{za } \lambda \ll r \quad \sigma = \pi \cdot r^2 \qquad (11.16)$$

$$\text{za } \lambda \gg r \; \delta \frac{144 \cdot \pi^2 \cdot r^6}{\lambda^4} \qquad (11.17)$$

11.1.3. TAPERING SHAPE

By rotating a circle around axis $\underline{z}$ we obtain the narrowing shape which is the constituent part of the vertex of all missiles and airplanes.

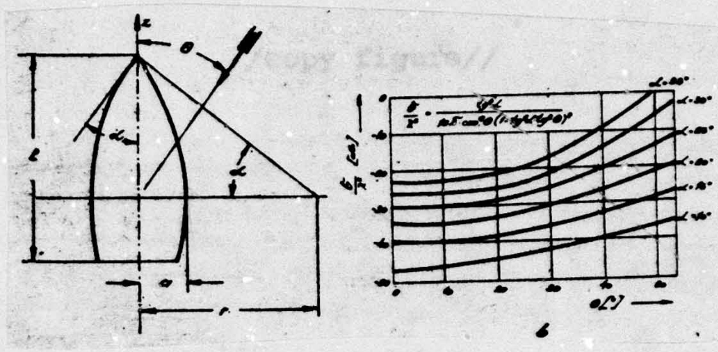


Fig. 11.6. a) Illumination geometry of narrowing shape, b) reflex surface as dependent on illumination angle θ.

If all marginal effects are disregarded and if the reflex surface is sought for illumination angles $0 \leq \theta \leq (90^\circ - \alpha)$, one obtains:

$$\sigma = \frac{\lambda^2 \, \mathrm{tg}^4 \alpha}{16 \cdot \pi \cos^6 \theta \, (1 - \mathrm{tg}^2 \alpha + \mathrm{tg}^2 \theta)^3} \tag{11.18}$$

where

at

$$\left(\frac{\lambda}{4\pi r}\right)^{\frac{1}{2}} < \alpha < \left[\frac{\pi}{2} - \left(\frac{\lambda}{4\pi r}\right)^{\frac{1}{2}}\right]$$

$$\theta = 90^\circ - \alpha$$

$$\sigma(90^\circ - \alpha) = \frac{r^2 \sin^2 \alpha}{4\pi} = \frac{a^2}{4\pi \, \mathrm{tg}^2 \frac{\alpha}{2}} \tag{11.19}$$

In the region $(90^\circ - \alpha) < \theta < 90^\circ$ one obtains:

$$\sigma = \pi r_1 \left(1 - \frac{r - a}{r \sin \theta}\right) \tag{11.20}$$

The symmetry of the body is such that

$$\sigma(\theta)=\sigma(\pi-\theta).$$

11.1.4. CONICAL SHAPES

Circular conus is a simplified shape of the nose of a rocket, whereas elliptical cone of a full or a truncated shape finds its expression more in the case of airplanes, wings, and similar bodies.

Truncated elliptical cone has a complicated reflex surface composed of two plane and one conical surfaces.

For rays which fall under normal angle onto the surface the reflex surface is:

$$\sigma\perp=\frac{8\pi\left(L_2^{\frac{3}{2}}-L_1^{\frac{3}{2}}\right)^2 \mathrm{tg}^4\alpha}{8\lambda\left(\frac{a}{b}\right)^2\cos^2\theta} \tag{11.21}$$

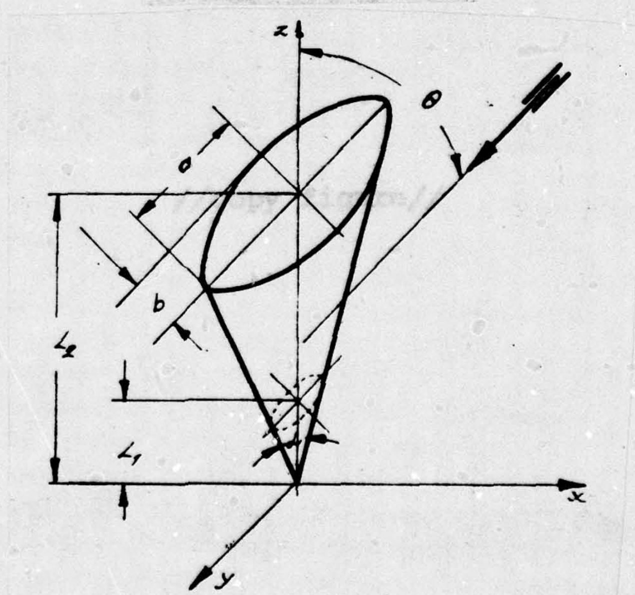


Figure 11.7.

Geometry of truncated elliptical cone.

The normal is determined by $\mathrm{tg}\,\theta=\frac{\frac{a}{b}}{\mathrm{tg}\,\alpha\left(\sin^2\Phi+\frac{a^2}{b^2}\cos^2\Phi\right)^{\frac{1}{2}}}$

For rays which fall at an angle of $\theta > \alpha$ the reflex surface is

$$\sigma = \frac{\lambda L \left(\frac{a}{b}\right)^3 \operatorname{tg}\alpha}{8\pi \sin\theta \left(\sin^2\Phi + \frac{a^2}{b^2}\cos^2\Phi\right)^{\frac{1}{2}}} \cdot \left[\frac{\sin\theta \left(\sin^2\Phi + \frac{a^2}{b^2}\cos^2\Phi\right)^{-\frac{1}{2}}}{\sin\theta \operatorname{tg}\alpha \left(\sin^2\Phi + \frac{a^2}{b^2}\cos^2\Phi\right)^{\frac{1}{2}} + \frac{a}{b}\cos\theta} - \frac{b}{a}\cos\theta \operatorname{tg}\alpha \right]^2 \quad (11.22),$$

(where L occupies the value either of L_1 or L_2, depending on which surface participates in the creation of the reflex surface).

Equationa 11.21 and 11.22 for the common truncated cone with $a = b$ assume the form

$$\sigma_{\perp} = \frac{8\pi}{9\lambda}\left(L_2^{\frac{3}{2}} - L_1^{\frac{3}{2}}\right)^2 \cdot \frac{\sin\alpha}{\cos^4\alpha} \quad (11.23)$$

$$\sigma = \frac{4L \operatorname{tg}\alpha}{8\pi \sin\theta} \cdot \operatorname{tg}^2(\theta - \alpha) \quad (11.24)$$

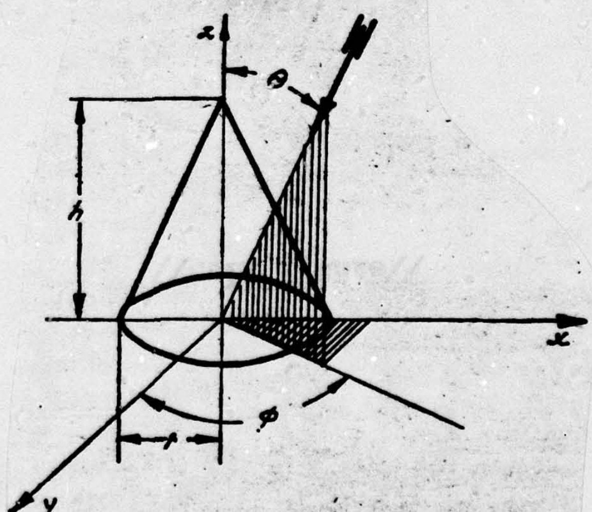


Figure 11.8.

Illumination geometry of common cone.

If one puts $L_1 = 0$ and $a = b$, the common cone is obtained, which is much used in rocket technology.

Radar reflex surfaces for various illumination angles are:

for $\theta = 0^\circ$

$$\sigma = \frac{\pi^3 r^4}{\left(\frac{3\pi}{2}+\alpha\right)^2} \operatorname{cosec}^2\left(\frac{4\pi^2}{3\pi+2\alpha}\right) \tag{11.25}$$

for $\theta = 180^\circ$

$$\sigma = \frac{4\pi^3 r^4}{\lambda} \tag{11.26}$$

for $\theta = \frac{\pi}{2} - \alpha$

$$\sigma = \frac{8\pi r^3}{9\lambda \cos\alpha \cdot \sin^2\alpha} \tag{11.27}$$

11.1.5. CYLINDER AND WIRE

When calculating radar reflex surface, the complicated shapes are frequently replaced by a cylinder. To replace sharp edges (edges of wings, etc.) a thin cylinder is always very suitable, with ($d \ll \lambda$), which corresponds to wire.

Elliptical cylinder

Radar reflex surface depending on angle of illumination is:
for $\theta = 90^\circ$

$$\sigma\perp = \frac{2\pi \cdot h^2 \cdot a^2 \cdot b^2}{\lambda\,(a^2 \cos^2\Phi + b^2 \sin^2\Phi)^{\frac{3}{2}}} \tag{11.28}$$

for $0 < \theta < 90^\circ$

$$\sigma = \frac{2\lambda\, a^2 \cdot b^2 \cdot \sin\theta}{8\pi \cos^2\theta\,[a^2 \cos^2\Phi + b^2 \sin^2\Phi]^{\frac{3}{2}}} \tag{11.29}$$

For common cylinder, where a = b, equations 11.28 and 11.29 are simplified into

for $\theta = 90°$

$$\sigma_\perp = \frac{2\pi h^2 a}{\lambda} \tag{11.30}$$

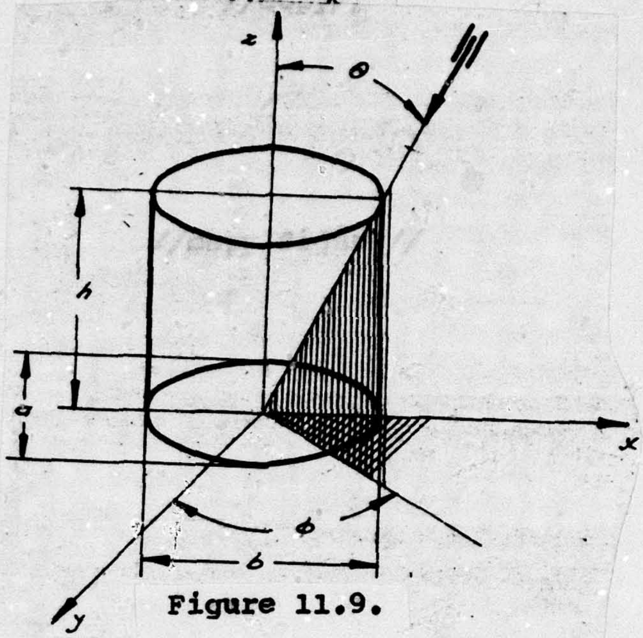


Figure 11.9.

Illumination geometry for a cylinder.

for $0 < \theta < 90°$ we have

$$\sigma = \frac{\lambda \cdot a \cdot \sin\theta}{8\pi \cos^2\theta} \tag{11.31}$$

For conducting wire with length $l \gg \lambda$ and diameter $d \ll \lambda$ one obtains as a suitable sample

$$\sigma = \frac{\pi l^2 \sin^2\theta \left\{\frac{\sin[(2\pi l/\lambda)\cos\theta]}{(2\pi l/\lambda)\cos\theta}\right\}^2}{\left(\frac{\pi}{2}\right)^2 + \left(\ln\frac{2\lambda}{\gamma \cdot \pi \cdot d \sin\theta}\right)^2} \cdot \cos^4\Phi \tag{11.32}$$

where γ is the coefficient and amounts to 1.78, l = length of the wire, d = diameter of the wire. For $\theta = 90°$, equation (11.32) simplifies to:

$$\sigma_\perp = \frac{\pi \cdot l^2 \cdot \cos^4\Phi}{\left(\frac{\pi}{2}\right)^2 + \left(\ln\left(\frac{2\lambda}{\gamma \cdot \pi d}\right)\right.} \tag{11.33}$$

The numerator in equation (11.32) can for the sake of simpler calculation be simplified. This simplification is valid within the range

$$\frac{\pi}{4} < \theta < \frac{\pi}{2}$$

and amounts to

$$\left(\frac{\pi}{2}\right)^2 + \left(\ln \frac{2\lambda}{\gamma \pi d \sin\theta}\right)^2 \approx \pi^2$$

For wires where

$$\frac{d}{2} \leqslant \lambda \ll l$$

it is established - on the basis of calculations and experimental data - that the equation for $\theta = 90°$ is very suitable

$$\sigma_{\perp} = \pi l^2 \left(\frac{d}{2\lambda}\right)^{0,57} \qquad (11.34)$$

On the basis of this equation, a nomogram for direct calculation has been made and is presented in Fig. 11.10.

If one wishes to obtain the reflex surface of a wire which is twisted in one plane, the following procedure is followed. On the basis for the equation for a cylinder the effective length of the wire (l_{ef}). is calculated. The reflex surface then is

$$\sigma = 2\pi l^2_{ef} \left(\frac{d}{\lambda}\right) = \pi \cdot d \cdot b$$

$$l_{ef} = \left(\frac{\lambda \cdot b}{2.}\right)^{\frac{1}{2}}$$

where: d = wire diameter,

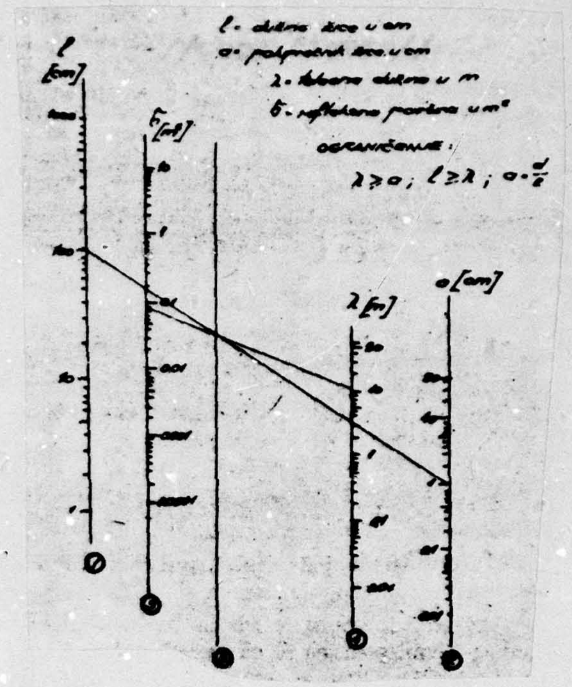
b = radius of the circle

this effective length is then put in equation (11.34) and one obtains

$$\sigma = \pi \cdot d^{0,53} \cdot b \cdot \lambda^{0,47} \qquad (11.35)$$

which is valid for

$$d \leqslant \lambda; \quad \left(\frac{\lambda b}{2}\right)^{\frac{1}{2}} \leqslant l \leqslant b,$$



Example: //somewhat illegible//

For wire with ℓ = 100 cm, diameter d = 2 cm (a = 1 cm) and wavelength λ = 10 cm we have σ = 0.09 m^2

Fig. 11.10. Nomogram for calculation of radar reflex surface of wire at $\theta = 90^o$. (Numbers under the columns indicate the order of withdrawing the direction. Determine ℓ on (1) and <u>a</u> on (2) and connect the points. Intersecting point on (3) connect with λ on (4). The obtained direction extend to (5) and here read the radar reflex surface (σ).

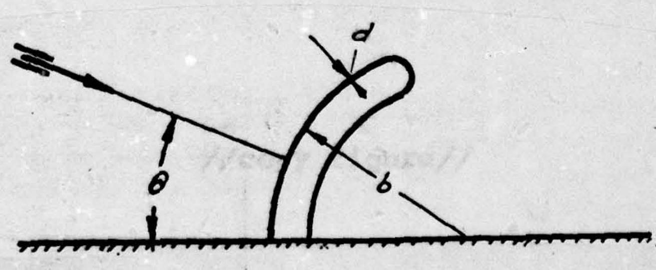


Fig. 11.11. Illuination geometry of twisted wire.

where ℓ = length of the twisted wire). On the basis of equation (11.35), the nomogram given in Fig. 11.12 is calculated.

11.1.6. TOROID

For the toroid case, which is with respect to the wavelength large, we have at $\theta = 90^{\circ}$ illuminated only the "reverse"* of the tsoid. Then the reflex surface is

$$\sigma = \frac{8\pi^2 \cdot b \cdot a^2}{\lambda} \qquad (11.36$$

---

*Reverse of toroid: An entire chapter of analytical methods is devoted to external surfaces of various geometrical shapes, which is why the term "reverse" or "inside" is more adequate that "internal face". Well, a toroid is a shape which has, depending which way one looks at it, both "external" and "internal" surfaces, even though in principle they are both external. Not being able to find a better term, the author feels that "reverse" or "inside" is ok to be used, and he hopes that the reader will understand this.

a = wire radius in cm

b = curvature radius in cm
//illegible//

λ = wavelength in m

θ = reflex surface in m^2

Limits:

$a \le \lambda$; $a = \frac{d}{2}$

$\sqrt{\frac{\lambda b}{2}} \le l \le b$

Fig. 11.12. Nomogram for calculation of radar reflex surface of twisted wire by equation (11.35). Numbers under the columns designate the order of withdrawal of the direction. Determine a (1) and b (2), connect them and extend to (3). Here connect point with λ (4). The intersection on (5) gives reflex surface δ.

At angle $\theta > 0$ the external and internal lateral surface are illuminated and then the reflex surface is

$$\sigma = \pi\left(\frac{ba}{\sin\theta} + b^2\right) + \pi\left(\frac{ba}{\sin\theta} - b^2\right) \qquad (11.37)$$

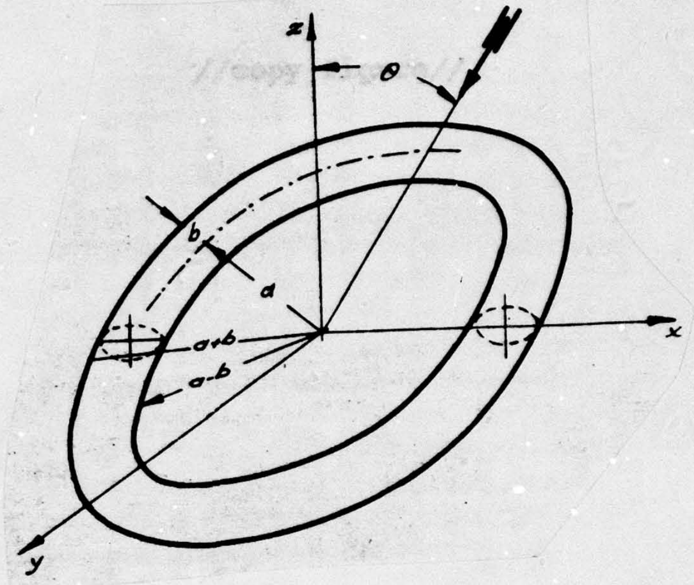


Figure 11.13.

Illumination geometry of a toroid.

The internal surface of a toroid gets into the shadow of the external ring at illumination angle $0 \leqslant \cos\theta \leqslant \frac{b}{2a}$ and then the second term of equation (11.37) drops out, and the expression for reflex surface assumes the form

$$\sigma = \pi\left(\frac{ba}{\sin\theta} + b^2\right) \qquad (11.38)$$

If b is very small with respect to λ, the torus can be replaced by a wire loop. This is always the case when one has, for instance, the illumination of a bottomless cylinder (the case of the trailing edge of a rocket engine). It is shown that to the reflex surface of a wire loop at $\theta = 0$ the following equation corresponds the most

$$\sigma \approx \pi a^2 \cdot \frac{\left(\frac{\pi}{2}\right)^2 + \left[\ln\left(\frac{85}{\gamma}\right)\right]^2}{\left(\frac{\pi}{2}\right)^2 + \left[\ln \frac{2\lambda}{\gamma \cdot \pi \cdot d}\right]^2} \qquad (11.39)$$

where: d = wire diameter (for edges $d = \frac{\lambda}{85}$)

γ = 1.78 (coefficient from equation 11.32),

a = radius of the loop.

11.1.7. COMBINED SHAPES

Long sharp edge. - If illumination geometry is such as in Fig. 11.14, then the reflex surface in dependence of the illumination angle Θ and edge angle γ is given by

$$\sigma(\theta, \gamma) = \frac{\pi l^2}{(2\pi - \gamma)^2} \cdot \left[\frac{\cos\beta_1}{1 + \sin\beta_1} \mp \frac{\cos\beta_1}{\sin\beta_1 + \cos\beta_2}\right]^2 \qquad (11.40)$$

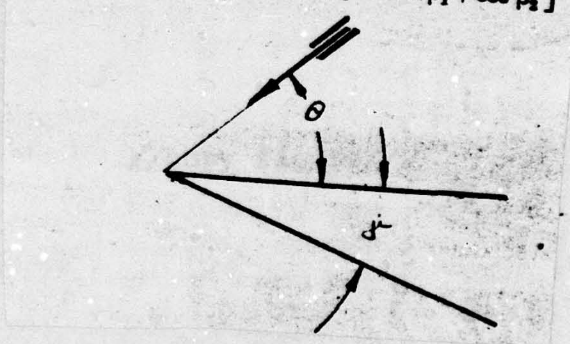


Figure 11.14.

Illumination geometry of long sharp edge.

where: l = length of the edge

$$\beta_1 = \frac{\frac{\gamma}{2}}{2 - \frac{\gamma}{\pi}}; \quad \beta^2 = \frac{2\theta}{2 - \gamma/\pi};$$

the sign $-$ is used if the vector of the electrical field is parallel to the edge, and the sign $+$ is used if the vector of the magnetic field is parallel to the edge.

Combination of cone with sphere (Fig. 11.15)

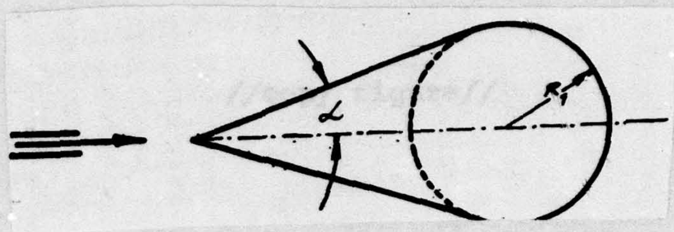


Figure 11.15.

Illumination geometry of cone-sphere combination.

The reflex surface during illumination from the front is

$$\sigma = \frac{\lambda^2 \cdot \mathrm{tg}^4 \alpha}{16\pi} \tag{11.41}$$

For cone-cylinder combination (Fig. 11.16) we have

$$\sigma = \frac{4\pi^3 a^2}{(\pi+\alpha)^2} \cdot \frac{\sin^2\left(\frac{\pi^2}{\pi+\alpha}\right)}{\left[\cos\left(\frac{\pi^2}{\pi+\alpha}\right) - \cos\left(\frac{2\pi^2}{\pi+\alpha}\right)\right]^2} \tag{11.42}$$

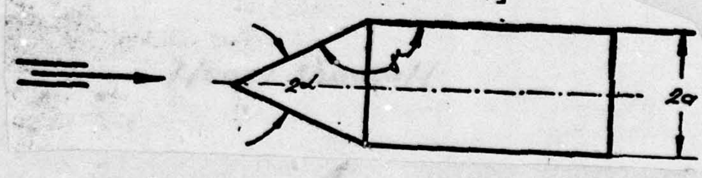


Figure 11.16.

Illumination geometry of cone-cylinder combination.

11.1.8. ANALYTICAL DETERMINATION OF RADAR REFLEX SURFACE OF AN OBJECT

The calculating method for the determination of radar reflex surface of a certain object basically consists of four phases of operation:

In the first phase the shape of the object is analyzed so as to divide it into parts which can be approximated by simple geometrical shapes for which the calculation of the reflex surface is known;

In the second phase the angular contribution of the total reflex surface for the specific parts from the previous point is determined;

In the third phase is calculated the reflex surface of individual parts of those illumination angles in which it contributes to the total reflex surface of the object;

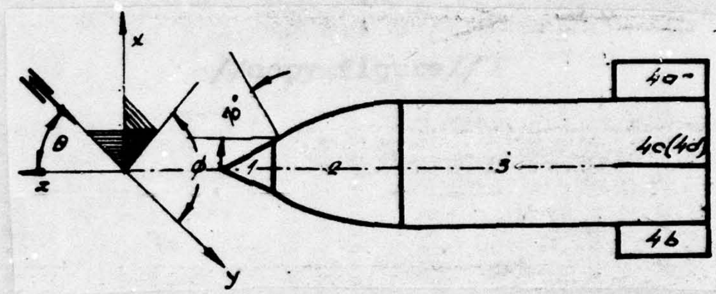


Fig. 11.17. Subdivision of a missile into elementary surfaces: 1 - cone, 2 - tapering (narrowing) shape, 3 - common cylinder, 4a, 4b, 4c, 4d - plane slabs.

In the fourth phase, the total theoretical radar reflex surface of the object is obtained from the sumtotal of the partial reflex surfaces found under point 3 for individual illumination angles.

The calculation is lengthy, especially for complicated shapes, which is why the electronic computer is usually used. In order to have the procedure more understandable, an example is presented for the procedure used for a more simple missile shape. Its subdivision into parts, per the first phase above, is given in Fig. 11.17.

Analysis of partial surfaces and their contribution to the total reflex surface shows:

that part 1 can be replaced by a cone,

σ_1 = contributes in illumination range $0 < \theta < 70^{\circ}$

-- reflex surface is calculated using equation (11.25);

that part 2 can be replaced by rotational--tapering shape;

σ_2 = contributes within illumination range $70^{\circ} < \theta < 90^{\circ}$

-- reflex surface is calculated using equation (11.20);

that part 3 is made up of two partial surfaces $\sigma_{3,1}$ and $\sigma_{3,2}$ of the cylinder and the loop by which the tail end of the missile can be replaced;

$\sigma_{3,1}$ -- contributes to illumination at $0 < \theta < 180^{\circ}$,

-- is calculated using equations (11.30) and (11.31);

$\sigma_{3,2}$ -- contributes to illumination at $\theta = 180^{\circ}$,

-- is calculated using equation (11.39);

that part 4 has 4 coverlets (4a,b,c,d)(equal to xz, -xz, yz, -yz) with different contribution to illumination range $0 < \theta < 180^{\circ}$ and $0 < \Phi < 180^{\circ}$. One must calculate the individual effects for various θ and Φ and then combine them in the total reflex surface.

$\sigma_{4,1}$, a -- $\sigma_{4,1}$, d -- contribution of front edge of coverlet at $\theta = 0^{\circ}$;

$\sigma_{4,2}$, a -- $\sigma_{4,2}$, d -- contribution of back edge of coverlet at $\theta = 180^{\circ}$;

$\sigma_{4,3}$, a -- $\sigma_{4,3}$, d -- contribution of side edges of coverlet at $\theta = 90^{\circ}$, $\Phi = 0, 90^{\circ}, 180^{\circ}, 360^{\circ}$.

The individual reflex surfaces are calculated using equation 11.34 or by nomogram of Fig. 11.10. For wire diameter one takes $\frac{\lambda}{85}$.

$\sigma_{4,14}$ a -- $\sigma_{4,17}$ d -- contribution of coverlet surfaces in the illumination range

$$0 < \theta < 180^\circ$$
$$0 < \Phi < 180^\circ$$

is calculated using equations:

- for $\theta = 90^\circ$ and $\Phi = 0^\circ, 90^\circ, 180^\circ$ by equation (11.7);
- for remaining angles Φ and θ by equation (11.8).

The overall reflex surface of the object for a certain angle is obtained by summation of individual reflex surfaces of the parts for the same angles Θ and Φ using equations (11.43).

$$\left.\begin{array}{l} \sigma(\theta_1, \Phi_1) = \sigma_1(\theta_1, \Phi) + \sigma_2(\theta_1, \Phi_1) + \cdots + \sigma_n(\theta_1, \Phi_1) \\ \vdots \\ \sigma(\theta_n, \Phi_n) = \sigma_1(\theta_n, \Phi_n) + \sigma_2(\theta_n, \Phi_n) + \cdots + \sigma_n(\theta_n, \Phi_n) \end{array}\right\} \quad (11.43)$$

11.2. EXPERIMENTAL CONFIRMATION OF RADAR REFLEX SURFACE

In case of most objects it is not possible to determine the radar reflex surface by means of calculations, not only because of the difficulties inherent in these calculations but also because of the impossibilities in foreseeing the mutual effects of the partial surfaces taken individually. This is why preference is given to experimental determination, which can be performed on the original

object or model, depending on the dimensions of the object and the wavelength used. If a model is used, the magnitudes of the object and the model must be put into ratios according to the following:

magnitude	real object	model
dimensions	l	$l' = l/n$
frequency	f	$f' = f \cdot n$
specific conductivity	γ	$\gamma = \gamma \cdot n$
dielectric constants	ε	$\varepsilon' = \varepsilon$
antenna amplification	G	$G' = G$
radar reflex surface	σ	$\sigma' = \sigma/n^2$

(where n is the factor of diminution of the model relative to the real object).

Measurements are performed on polygons specially outfitted for this purpose or, in the case of small models, in special spaces in which the "reflection" of electromagnetic waves from the walls is reduced to a minimum. Basically, the following principles must be adhered to:

first, electromagnetic field upon arrival at the object to be measured must be homogeneous and with an even front (in the vicinity of the antenna the front is spherical);

secondly, reflections from the objects in the vicinity of the object to be measured should be minimal;

thirdly, the fastening of the object to be measured on the stand, as well as the stand itself, must be such that it has no effect on the distortion of the electromagnetic field and that they do not reflect electromagnetic energy and thereby increase the reflex surface of the measured object;

fourthly, prior to the start of each measurement, calibration of the measuring apparatus must be done, and this so that an object of a known reflex surface is used. The most convenient for this is a sphere, since its reflection does not depend on the direction of illumination.

As measuring apparatus can serve the radar installation itself if it has a calibrated receiver. The antenna with which the object to be measured shall be illuminated must have as narrow a beam as possible and minimal side fans. The optimal beam width ($\Delta\beta$) corresponds to the width of the object to be measured (d) at the

distance of the measurement (x) increased by factor (k)

$$\Delta \beta_{opt} = k \cdot 57{,}25 \ \frac{d}{x} \tag{11.44}$$

where: k = 1.1 - 1.2; d = width of object measured in m; x = distance of object measured in m; $\Delta\beta_{opt}$ = optimal width of antenna beam).

If pulse-radar installation is used the distance between the object measured and the transmitter-receiver antenna of the radar depends on the duration of the radar pulse and must be at least:

$$d \geqslant \frac{c \cdot \tau}{2} \tag{11.45}$$

where: d = distance between the object measured and the radar in [m],

c = velocity of light [$3 \cdot 10^8$ m/sec]

τ = pulse duration in [μ sec]

2 = due to two-way path.

If radar with pulse duration τ = 1μsec is used, the distance between the object measured and the radar must be at least d$\geqslant$150 m. Due to relatively large distances which classical radars demand and due to the problems associated with this regarding diminution in reflection from surrounding objects, special radars with short pulse duration (from 0.01 to 0.1μsec, which corresponds to the distance 1.5 to 15 m) must be employed.

Another element which limits the application of pulse-radar at short distances is the ionization tube which is used in the receiving and transmitting movement and the duration of its deionization at the end of the transmitting pulse. This can be avoided by using special transmitter and receiver antennas.

Due to the limitation of the pulse-radar regarding its application for the determination of the radar reflex surface, other methods have been developed using continual radiation by means of doppler effect (see p. 225 of copy, equations 9.11-9.13).

The first method makes use of a resting object to be measured, a transmitter with rigidly stabilized and variable frequency with time ($\frac{df}{dt}$) and a receiver which at its input has a rigidly selective filter for doppler frequency change which amounts to

$$f_D = f_{prij} - f_{pred} =$$
$$f_D = \left(f_{pred} + \frac{2d}{c} \cdot \frac{df}{d_t}\right) - f_{pred} = \frac{2d}{c} \cdot \frac{df}{dt} \qquad (11.46)$$

where: f_D = doppler frequency

f_{trans} = transmitting frequency (f_{pred})

f_{rec} = receiving frequency (F_{prij})

d = distance between antenna and object measured

c = velocity of light.

The objects which are located at other distances from the object measured will give a different doppler frequency change and can be eliminated by a selective filter. The radar reflex surface is proportional to the amplitude of the signal at frequency f_D. The absolute values of the reflex surface is obtained by comparison with the reflected signal of the known object, generally a sphere having the corresponding diameter (according to the dimensions of the object measured).

In the second method, a transmitter with stable frequency and narrow antenna beam is used. The object to be measured is positioned on one leg of the stand which is rotated at a constant rate. On the other leg is positioned the sphere which is used as the standard. Due to

the rotation there again occurs doppler frequency change as per

$$f_D = \pm \frac{2v}{c} \cdot f_{pred} \tag{11.47}$$

where:

v = rate of motion of measured object

c = velocity of light

f_{pred} = transmitting frequency (f_{trans})

$\pm$ = depending on direction of motion.

On the receiver side, a special selective filter is used to single out the doppler component of the frequency change. Its amplitude is compared with the same signal from the standard from which the value of the reflex surface is deduced.

From what has been said above it is seen that experimental methods are rather complicated and have many shortcomings. Which method will at any given instant be used depends on the measuring apparatus that is available, the measuring site or polygon and, on site, on the magnitude of the measured object.

XII FALSE TARGETS -- RADAR BAITS

The methods heretofore described for the creation of false radar echoes have produced false targets on radar display screens in the direction radar--carrier of installation with earlier or later indication (point 8.1.6., p. 200 of foreign copy, and point. 9.1.3. on p. 233 of foreign copy), from the indication of the signal. By comparing the radar data from two neighboring radar installations one can, thanks to the fact that false echoes are situated on the radar--carrier line, separate the false echoes from the true echoes, since the false echoes will appear on different coordinates, and the true echoes always at the same place. Figure 12.1 shows the case of a true

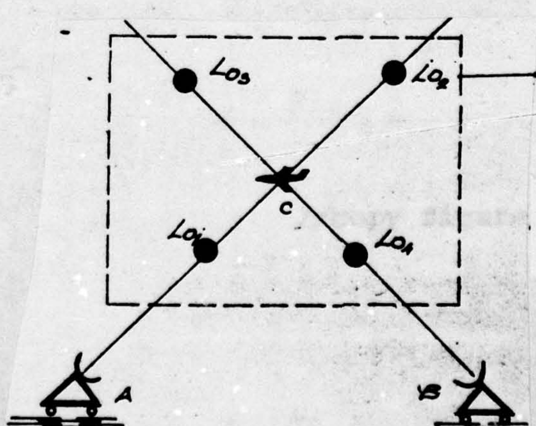


Fig. 12.1. Selection of false from true echoes; LO_1, LO_2, LO_3, LO4 - false echoes; C - true echo.

target, which gives two false echoes each for radars A and B. Radar A sees target C and false echoes LO_1 and LO_2. Radar B sees target C and false echoes LO_3 and LO_4. In either radar installation it is only target C that is shown so that its coordinates coincide and is hence the true target. For targets LO_1, LO_2, LO_3, and LO_4 the coordinates do not coincide and hence they are false echoes.

To avoid the possibility of selecting false from true targets and to have the false targets appear at some other azimuth with respect to the true target, false targets - the so-called radar baits - have been introduced in the rich arsenal of electronic countermeasures.

False targets in this case are aircraft or floating objects which the true target uses in one of the following ways (Fig. 12.2):

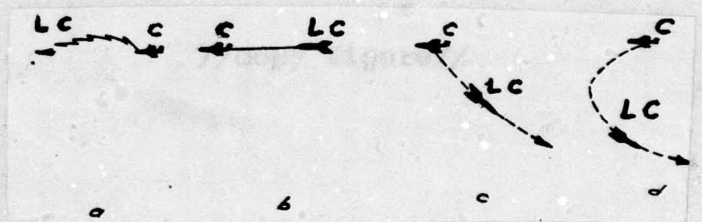


Fig. 12.2. Ways of application of false targets -- radar baits; LC - false target; C - true target.

- it drives them in front of itself (a);
- it pulls them behind itself at a distance of several kilometers (b);
- it throws them out of the airplane (c), and
- it launches them with short-term natural own drive (d).

When one has to do with floating objects, only the first two ways come into consideration.

The false target -- radar bait -- can be either active or passive. In the former case it is equipped with an active responder, and in

the latter case it carries passive reflectors for the sake of increasing its own radar reflex surface.

Radar echo from a false target possesses all the components of a true echo: signal amplitude, direction of motion, velocity, and acceleration. Because of this, the separation of a false echo produced in this way from a true echo is not possible by technical means.

Tactically, the application of false targets has the following effects:

- it confuses the radar operator and hinders him from determining the importance of the target,
- it increases the load on the channel for the transmission of the data to saturation, and
- it increases the consumption of striking means of the PVO (airplanes, rockets, or grenades) for false targets.

If the true target is protected by several false targets, then the probability of its destruction can be calculated by equation

$$P_{n(m)} = \frac{m}{n} P \qquad (12.1)$$

where: n = total number of targets (sum of false and true ones)

m = number of rockets fired (salvos);

P = general hit probability by fired rocket or salvo.

Equation (12.1) is valid for the case when a) the number of fired rockets is less than the number of targets $m < n$ and b) when false and true targets are equivalent. From equation 12.1 it is seen that in case that the true target is concealed by one false target the

general hit probability will decrease by 50%, when it is concealed by two false targets, it will decrease by 66.6%, and so on.

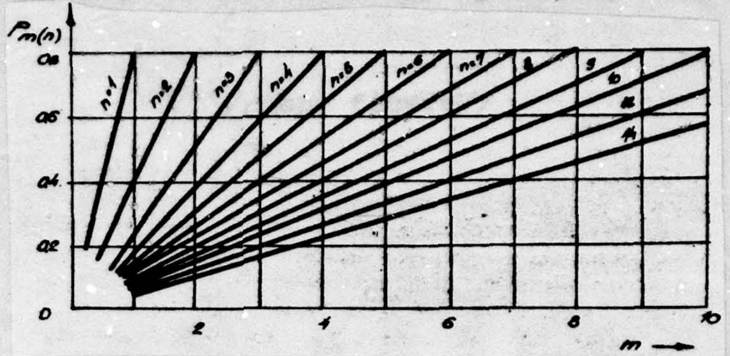


Fig. 12.3. Probability of destruction of true target surrounded by n - 1 false targets after m fired rockets with individual hit probability P = 0.8.

Equation 12.1 can for the given missile with known hit probability be expressed as in Fig. 12.3, where the dependence of destruction of one true target $P_{m(n)}$ protected by (n-1) false targets after m fired rockets and with an intrinsic hit probability P = 0.8 is shown.

From equation 12.1 and Fig. 12.3 it follows that the effectiveness of the enemy PVO can be reduced to the minimal value if the true targets are surrounded by a sufficient number of false targets -- radar baits. The large number of radar baits necessary is, taken as a whole, also the only shortcoming of this kind of countermeasures.

12.1 GUIDED FALSE ECHO

False echo -- radar bait -- can be launched in all directions around the carrier. In case of the airplane as the carrier, the false targets are either pilotless airplanes or rockets with own drive and maneuvrability; by radio-guidance the airplane carriers are kept at a certain distance.

False targets are equipped with:

a) passive reflectors with radar reflex surface at least equal to the true target:

$$\sigma_{\text{false target}} \geq \sigma_{\text{true target}} \qquad (12.2)$$

(Calculation of passive reflectors is given in point 10.1, p. 246 of copy. .

b) active responder of the "transponder" type, with output power corresponding to the reflex surface of the concealed target. The radiation diagram for receiver and transmitter antenna must be as similar as possible to the distribution of the reflex surface of the true airplane. In the first approximation, the radar reflex surface of the airplane can be replaced by a sphere, which therefore means that the radiation diagram of the receiver and transmitter antenna on the bait must also be spherical.

On the basis of equation (8.21) the necessary power, P_C , is obtained which the transmitter must radiate at the false target

$$P_{LC} = \frac{P_i \cdot G_{rad} \cdot \sigma}{4\pi \cdot R^2 \cdot G_{LC}} \qquad (12.3)$$

where: Pi = radar pulse power;

c = radar antenna amplification;

G_{rad} = false target antenna amplification (for spherical radiation diameter we have Gc = 1);

σ = radar reflex surface of the target which is to be protected;

R = radar--false target distance.

If the false target is located at a distance from the true target which is less than or equal to angular or distance separation of the radar, the false and the true targets melt into one.

The separation of the radar by coordinates (Fig. 12.4) is given by:

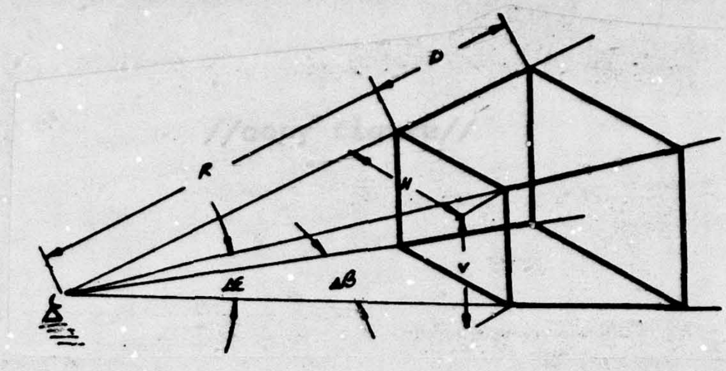


Fig. 12.4. Separation of radar by coordinates.

separation by distance $D=\frac{c\tau}{2}$ (12.4)

separation by azimuth $H=\frac{\pi\cdot\Delta\beta\cdot R}{180}$ (12.5)

separation by elevation $V=\frac{\pi\,\Delta\varepsilon\cdot R}{180}$ (12.6)

where: τ = radar pulse duration;

c = velocity of light;

$\Delta\beta$ = azimuthal beam width,

$\Delta\varepsilon$ = elevation beam width

R = distance.

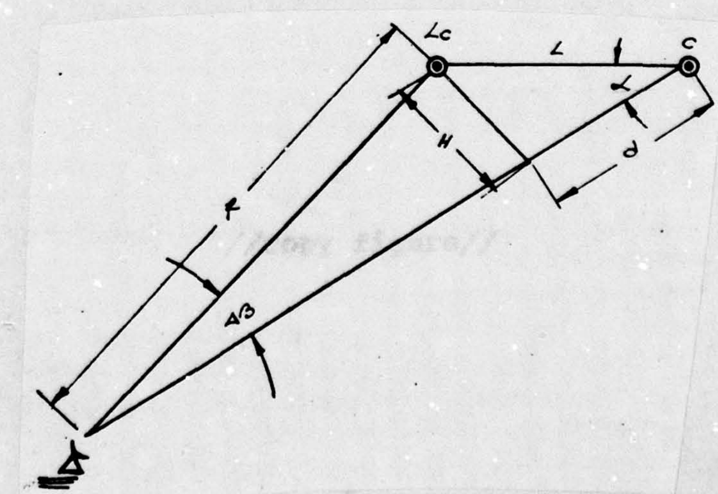


Fig. 12.5. General case of interrelationships between radar A with beam width $\Delta\beta$, false target LC and true target C.

356

From the general case of the interrelationships between the radar, the false target, and the true target, such as shown in Fig. 12.4, one obtains the maximal distance between the true target and the false target

$$L \leqslant \frac{H}{\sin \alpha} \tag{12.7}$$

The distance component of the position must thereby always be within the separation (resolution) boundaries by distance

$$d - L \cos \alpha \leqslant D \tag{12.8}$$

12.2. PULLED FALSE TARGET

An airplane or a ship can pull a false target behind themselves. If they pull it at a distance which is smaller or equal to resolution capabilities of the radar by coordinates (equations 12.4 to 12.8), the same merging effect of the true and the false target appears on the radar, with coordinates which correspond to the middle between the true and the false target.

The pulled false target can also be used as a "bait" for anti-aircraft rockets. In this case, all the way to the instant of launching the rocket towards the airplane, the false bait with the reflex surface larger than that of the airplane which it protects is present either on or in the airplane. At the instant that the guiding of the rocket toward the airplane commenced, the false target separates and its distance slowly increases. The rocket transfers from true target to false target. This method is especially successful against rockets having their own self-guidance systems and in case of night fighters equipped with self-guidance (autopilot) installations.

12.3. EJECTED FALSE TARGET

Ejection or throwing out of false target from the airplane is used as protection of the airplane against anti-aircraft rockets or interceptor fighter planes equipped with autopilot (under night conditions).

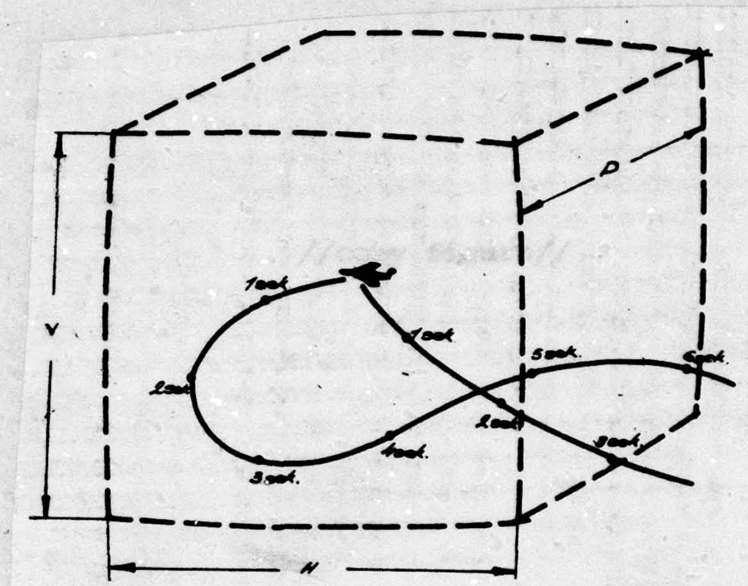
For ejected false target to be effective, the following conditions must be fulfilled:

- radar reflex surface for it must be considerably larger than the radar reflex surface of the airplane which it is protecting,
- its falling (descent) rate must be such that it can sustain itself as long as possible in the space limited by the resolution capabilities of the radar by coordinates. This is so that the radar for self-guidance on the rocket would for sure "hook" onto the false target.

The falling rate is determined by the weight, as well as the ballistic and aerodynamic properties of the false target. Since even the most favorable properties do not make it possible for the false target to sustain itself in the air for sufficiently long time, the false target is equipped with a small motor. Several seconds after the launching the motor sharply turns the false target and works a few seconds more. The result of this maneuver is: longer sustenance in the space limited by separation capabilities of the radar. Figure 12.6 shows the route of the ejected false target with own drive (b) and without such drive (a) inside the space limited by separation capabilities of the radar by distance D (equation 12.4), by azimuth H (equation 12.5), and by elevation V (equation 12.6).

The radar reflex surface on the false target must be considerably larger than the radar reflex surface of the airplane which the false target is protecting. In practice, it suffices that

$$\sigma_{\text{false target}} \leqslant 5\text{-}10\ \sigma_{\text{true target}}$$



sek = sec

Fig. 12.6. Ejection of false target: a - without drive, b - with own drive mechanism.

Such a large reflex surface is obtained by combining passive reflectors (point 10.1.1., p. 246 of copy   or by combining passive reflectors with active responders (point 10.1.1., p. 246 of copy.

XIII EFFECT OF NUCLEAR EXPLOSIONS ON ELECTRONIC EQUIPMENT

Nuclear explosions, especially high-altitude ones, have an important characteristic and multiple effect on the operation of electronic equipment.

The explosion of a nuclear bomb equivalent to 1 Mt of conventional TNT explosive produces approximately 10^{33} free electrons (β-particles). This quantity approximately corresponds to the total number of free electrons in the Earth's ionosphere. Through the explosion, a tremendous amount of energy (approximately 10^{IS} calories) is liberated within a very short time (less than 1 microsecond). The consequence of this are tremendous changes in pressures and temperatures, Besides this, the energy of the explosion also creates x- and γ-rays and neutrons of various velocities. The consequences are: shock (impact), light, thermal, electromagnetic, and ionization effect, with different action on people and electronic equipment. Here we shall talk only about the effect of nuclear explosion on electronic equipment.

13.1 EFFECT OF SHOCK WAVE

During a high-altitude or surface nuclear explosion a shock wave is created which propagates at a rate of 350-450 m/sec from the center of explosion toward the periphery, by its power destroying all the obstacles that are in the way. 360

Even though electronic equipment is in most cases located in such a way that it is protected more or less from the direct action of shock waves, their antennas are in every case - due to the required propagation of electromagnetic waves - the most exposed. Out of the antennas, the most exposed are antennas of radar navigational and radar-relay equipment and facilities, since for their optimal operation they are set up on exposed points of the terrain.

Therefore, shock waves due to nuclear explosions destroy antenna systems of electronic equipment and facilities.

13.2 EFFECT OF IONIZATION RADIATION

The tremendous amount of liberated electrons, x- and γ- rays, as a result of nuclear explosion, and also the large current of neutrons of various velocities has a twofold effect on the operation of the electronic equipment. First, due to radiation the properties of the material and the element from which the electronic equipment is made change, and secondly, the free electrons and explosion products create at the explosion site an ionized cloud, which in turn attenuates, reflects, or introduces greater or smaller degree of refraction in the itinerary of electromagnetic waves. Therefore, changes in the way of propagation of electromagnetic waves are the other effect of ionizing radiation.

Changes in the properties of the material

Under the effect of ionizing radiation there occurs a change in the properties of the material from which the components of the electronic equipment are made and hence changes occur in its individual or combined performance.

361

The changes in the properties of irradiated material can be temporary and permanent. The temporary ones are present on the material only during its exposure to ionizing radiation. After the cessation of radiation, the material again assumes its initial properties. In permanent changes, the changes remain present also after the irradiation of the material or the element has ceased. These changes result in that the electronic equipment under radiation of lesser intensity operates with altered performance or there can even be a short-term break in its operation. With increased radiation, total breakdown in the operation of the electronic equipment can occur due to permanent changes in the material or the elements.

The main properties of the electronic equipment components which change under the effect of ionizing radiation are given in Table 13.1.

Tests have shown that there exists a different dependence of the change in the properties of various electronic components on the strength of ionizing radiation, i.e. on neutron current and γ-radiation. The results of these tests are shown in Figs. 13.1 and 13.2. The start of the effect (left end of compact line) corresponds to the exposure dosage at which the first permanent changes in the properties of a component part of an electronic equipment are noticed. These permanent changes make it impossible to have the particular component part function in a regular fashion, thereby affecting also the operation of the electronic equipment as a whole.

By suitable selection of the elements which the electronic equipment is composed of, their sensitivity to ionizing radiation can be reduced to a minimum.

components	critical properties of electronic equipment components which change under the effect of ionizing radiation	
	temporary change	permanent change
resistors	resistance, especially with high-ohmic ones	resistance
condensers	dielectric constant and losses in insulator	capacitivity (capacitance)
vacuum electronic tubes	currents of individual electrodes	cathodic emission, electrode currents, steep slope characteristic
electronic tubes filled with gas	ignition tension	ignition tension: anode-cathode, cathode net; extinction tension: anode-cathode
semiconductor diodes	conducting current	change in the characteristics
transistors	current through transistor	Change in the characteristics and amplification factor
photo-diodes	"dark" current	sensitivity
photo-resistors	"dark" resistance	sensitivity
combined elements	insulation resistance electrical conductivity	insulation resistance, conductivity, contact resistance

Table 13.1. Critical properties of electronic equipment components which change under the influence of ionizing radiation.

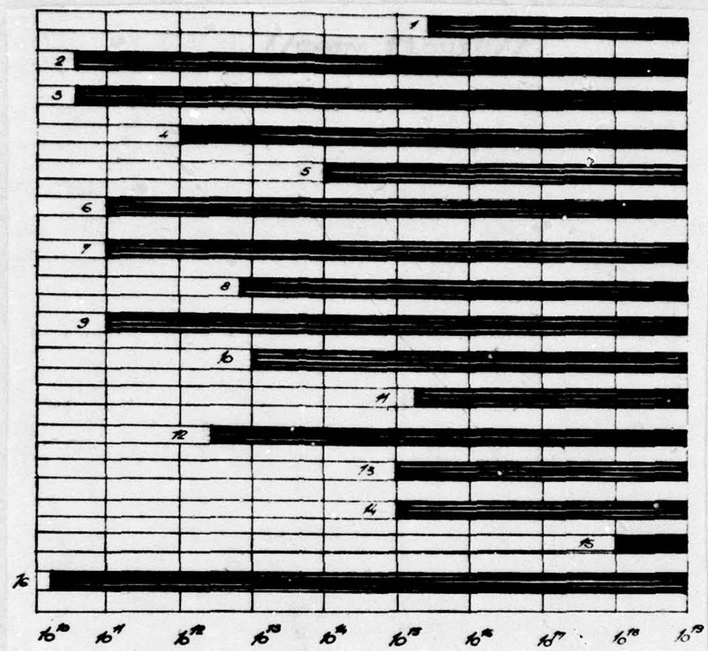


Fig. 13.1. Change in the properties of electronic elements as a function of the neutron current: 1 - electronic tubes, 2 - semiconductor diodes, 3 - germanium diodes, 4 - silicon diodes, 5 - Zener diodes, 6 - transistors (28 kinds with different base thicknesses), 7 - NF germanium transistors, 10 - VF silicon transistors, 8 - VF germanium transistors, 9 - NF silicon transistors, 10 - VF silicon transistors, 11 - resistors, 12 - converters, 13 - magnetic materials, 14 - permalloy, 15 - transformer plate, 16 - solar cells.

Effect on propagation of electromagnetic waves

Neutrons, γ- and x-rays, ultraviolet radiation, and a large number of β particles after a nuclear explosion ionize the atmosphere, as a result of which there occurs attenuation, reflection, or refraction in the route of the electromagnetic waves if they pass through an ionized region.

Right after a nuclear explosion there appears a small fiery ball which introduces so much attenuation that it is totally "nontransparent"

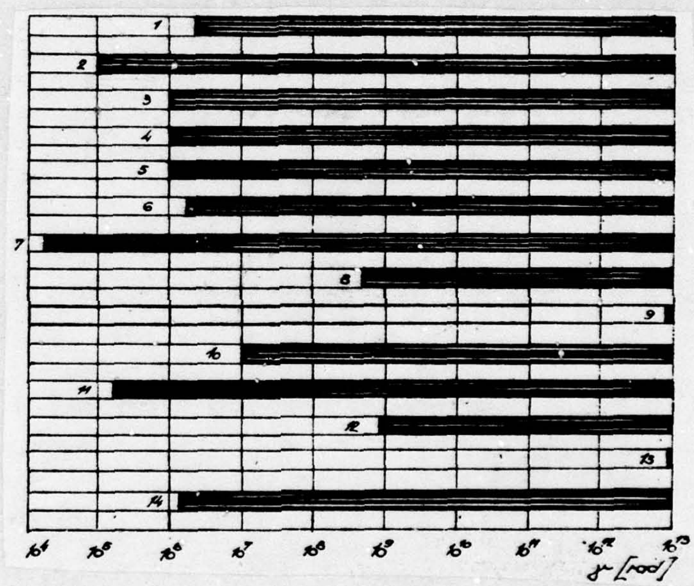


Fig. 13.2. Change in the properties of the material and elements used in electronics as a function of ionizing radiation dosage: 1 - phosphors, 2 - optics and optical glasses, 3 - IC-technology elements, 4 - light-sensitive elements (photo-elements), 5 - resistors, 6 - batteries, 7 - teflon, 8 - polystyrene, 9 - ceramics, 10 - condensers, 11 - tantalum condensers, 12 - polystyrene condensers, 13 - mica condensers, 14 - electronic tubes.

for electromagnetic waves. If the itinerary (route) of the electromagnetic waves passes through the center of a nuclear explosion, it at that instant becomes disrupted. As the fiery ball rises and expands, its temperature decreases and it becomes "transparent."

Attenuation as a function of electron concentration in the atmosphere is given by expression:

$$\beta = \frac{0,45 \cdot 10^{-3} \cdot n}{f^2} \tag{13.1}$$

where: n = number of electrons per m^2,

4 = frequency in Hz,

β = attenuation in db/km.

On the basis of equation (13.1) one can calculate the required electron concentration per m^2, by virtue of which attenuation is introduced at frequency f. The required number of electrons is given by:

$$n = \frac{\beta \cdot f^2}{0,45} \cdot 10^3 = 2,22 \cdot 10^3 \beta \cdot f^2 \tag{13.2}$$

As can be seen from expression (13.1), attenuation at higher frequencies is smaller than attenuation at lower frequencies. This means that "nontransparency" of ionized atmosphere for short wavelengths will be shorter in time than the "nontransparency" for longer wavelengths.

On the altitude at which nuclear explosion occurs depends also the duration of the ionization effect. This is so because the lifetime of free electrons (energy loss) increases with increased altitude, due to the rarer air there. In dense air, at sea level, the average lifetime of free electrons is approximately one microsecond. This means that nuclear explosions at altitudes below

15 km will not result in abundant attenuation. Disturbances will occur only in communications which use reflection from the ionosphere (space wave in case of KT communications, troposcatter communications). These disturbances or interferences can last also for several hours, depending on the wavelength and electron concentration.

13.3 ELECTROMAGNETIC EFFECTS

At the very instant of nuclear explosion, i.e. as the "fiery ball" forms and then all the way until its decomposition, two electromagnetic effects show up. They are: powerful electromagnetic pulse and electromagnetic radiation of thermal origin at all the frequencies, including here at the frequencies of the radar and radio signals.

The most damaging effect on electronic equipment, besides the ionization effect, is produced by electromagnetic pulse.

Electromagnetic pulse is the consequence of very fast motion of a very large number of electrons and ions at the instant of the explosion. The signals which appear thereby have a very wide frequency spectrum, from low to very high frequencies. Their propagation is radial from the center of the explosion, similar to the propagation of light. The electromagnetic pulse can enter the electronic equipment either through the antenna or through induction via cables, lines, or conductors. In addition, the strong magnetic field changes the properties of the magnetic materials (magnets, magnetic memories, polarized relays, etc.).

In the first case, i.e. during the entry of the electromagnetic pulse via the antenna, an extremely strong signal arrives in the electronic installation, so much so that it destroys the input poles of the electronic equipment.

In the second case, very high voltages (10-50,000V) can be induced in the cables, lines, and conductors, which - due to the high current they produce - destroy everything as they go along. For instance, in case of high-frequency wire or cable communications the burning out of the conductors, line amplifiers, terminal stations, telephone exchanges, and similar. Tests have confirmed that the duration of the electromagnetic pulse is several milliseconds, that its component in the frequency range from 10 to 15 KHz penetrates also up to 90 meters deep into the ground, and that its effect is felt - depending on the strength of the explosion - also at a distance of 50 to 300 km from the center of the explosion.

In another case, in the creation of a noise signal at the input into electronic equipment the "fiery ball" takes part as the source of it. It is first small and extremely hot. With passage of time, it rises, expands, and cools. During all this time it radiates electromagnetic waves, depending on its temperature (see point 7.1.5, p. 199 of copy , and equations 7.33 and 7.34). In electronic installations with sensitive receivers and very large antennas, especially if the antennas are directed in the direction of the explosion, there occurs a degradation in the sensitivity of the receivers in a manner similar to wide-band jamming by noise. The interference lasts until the "fiery cloud" sufficiently expands and sufficiently cools down. The average time that this lasts is several minutes.

Besides the enumerated effects as the consequence of an air nuclear explosion there emerges also synchronic noise generated by the free electrons, the β-particles. These particles circulate in a spiral fashion around the geomagnetic field lines and they travel hours and days from the northern to the southern hemisphere until it disappears. The effect has been confirmed in 1958 at the occasion of a nuclear explosion at the altitude of 300 km. The electrons formed a "core" around the Earth, measuring 100 km in thickness, which traveled around the Earth for several hours. Since the strength of synchronic noise drops approximately with the fourth power of the frequency and has a radial orientation (normal to the geomagnetic field), the synchronic noise is not a serious factor in the degradation of electronic equipment. Its effect is observed only in case of highly sensitive astronomic electronic installations.

XIV

THE DESTRUCTION OF ELECTRONIC INSTALLATIONS

Belgrade ELEKTRONSKA PROTIVDEJSTVA in Serbo-Croatian 1971 pp 326-331

[Chapter 14 from the book "Elektronska Protivdejstva" (Electronic Countermeasures) by Aleksandar Razingar, published in the "Our Writers" Military Library]

[Text] Though every day they are experiencing increasing development and application, the methods and means of active and passive electronic countermeasures cannot completely prevent the operation of electronic equipment and systems. That is because the effect of electronic countermeasures is dependent on when they are applied and the conditions for propagation of electromagnetic waves. However, if one wishes to completely neutralize a particular piece of electronic equipment, its physical destruction is still the most effective way of doing so.

If a piece of electronic equipment is to be physically destroyed, one must first have precise data on its location. The data are obtained by electronic reconnaissance, from agents, or in some other manner.

The methods of destroying electronic facilities depend on their distance and accessibility. In principle they can be divided into the methods of destroying nearby and accessible electronic facilities and methods of destroying distant or inaccessible electronic facilities.

The capability of physical destruction of a piece of electronic equipment compels the user of that equipment to keep it in constant movement, to maintain strict security concerning plans governing its movement, and to have reserve positions prepared and tested in advance.

Since it is very difficult to achieve this kind of organization of the constant movement of a piece of electronic equipment (or system), so that its operation at all positions would be optimal in every respect, the countering effect achieved by physical destruction is actually dual. The duality is manifested in the less-than-optimal operation of the device because of its constant movement, and second, in interruption of the operation because of the destruction. In many cases the result of the first effect is itself inadequate.

14.1. Methods of Destroying Nearby Electronic Facilities

By "nearby" electronic facilities we mean those which are located in the vicinity of the border, the front, etc. Their distance from the enemy is such that they are in the range of the conventional weapons the enemy possesses.

Artillery, mortars and sometimes airplanes and demolition teams are used for destruction.

Since these are methods of a tactical nature, we shall not elaborate on them here.

14.2. Methods of Destroying Distant Electronic Facilities

By "distant" electronic facilities we mean those located in the enemy's rear beyond artillery range. Bombing, airborne landings or demolition teams have been used to destroy such facilities, and they are still in use today. For the action to be successful, one obviously must know the precise location of the electronic facilities. Since only the approximate location can be determined with the methods of electronic reconnaissance, these data are supplemented with the information from aerial photographs. All of these procedures mean time spent in preparation, and the more complicated the action, the longer that time will be. If the electronic facility should be moved to another position during those preparations, all the work done has been in vain. Special passive electronic homing devices have been developed to overcome this; they use the signal emitted by the facility to be destroyed as a navigation radio beacon. In this case it is not even necessary to know the precise location of the electronic facility; it is sufficient to know its frequency and mode of operation. The passive homing devices are mounted in airplanes or missiles.

The airplane passive homing device consists in principle of a receiver, an indicator and an antenna with a highly directional characteristic (Figure 14.1). The highly directional antenna beam is set at a small eccentric angle $\Delta\beta$ with respect to the airplane's axis. The antenna beam is mechanically or electrically rotated.

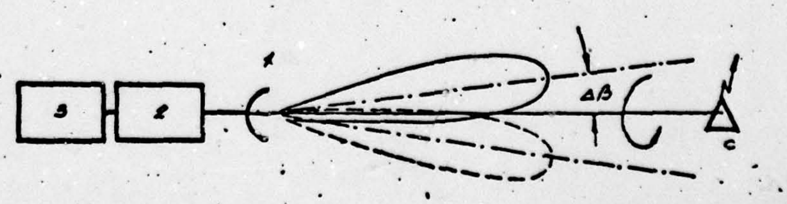


Figure 14.1. Principle of the aircraft passive homing device: 1--antenna; 2--receiver; 3--indicator; C--facility being homed on.

The receiver compares the signal received from the respective quadrants of the antenna's rotation. If all four incoming signals are equal, the source

of the radiation is located in the direction 1-C, i.e., in the equal-signal zone. It is customary to install the device on the aircraft so that the equal-signal zone coincides with the axis of the aircraft's flight.

If the signals received from the different quadrants are not equal, that means that the line from the aircraft to the target does not coincide with the flight axis. The pilot must handle the plane so as to equalize the signals received and thereby bring the aircraft into the position where the flight axis and direction to the target coincide.

This method of passive homing is quite precise, particularly since it increases as the distance decreases, because at smaller distances the widths of antenna beam are smaller.

From the technical standpoint there are several methods of design from a rotating antenna with switching to a multielement antenna at rest which is connected to multichannel receivers.

A device which begins homing at distances up to 1,500 km has been installed on the American F-105 fighter. The aircraft is led to the target area with an accuracy of ±200 meters. Heavy bombs are used as a weapon to destroy an electronic facility, and the use of tactical atomic bombs is also envisaged.

Because of the possibility of the aircraft's being destroyed on its way to or from the target and especially in the area of the target, which, if it is important, is usually well defended with air defense facilities, missiles have been developed to destroy electronic facilities.

Missiles for destroying electronic facilities consist in principle of a passive homing guidance device which is usually located in the tip of the missile, the explosive part, the solid-fuel or liquid-fuel propulsion system and the flight control assembly. The missile is launched from an aircraft at a safe distance from enemy air defense (15-80 km) in the direction of the electronic facility one wishes to destroy (Figure 14.2).

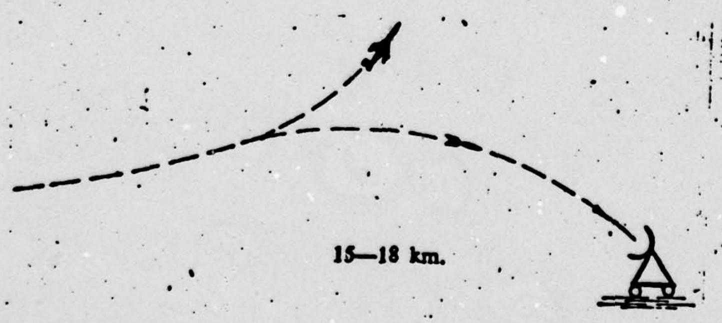


Figure 14.2. Launching a missile for homing guidance on an electronic facility.

In principle the head of the missile used for homing guidance consists of an antenna, a receiver and a control device. The antenna may emit a beam which rotates eccentrically, or four simultaneous beams, one for each quadrant. In the first case one receiver is needed with switches at the input and the output; in the latter one needs four receivers, one for each quadrant (Figure 14.3). The input signal from the antenna A arrives through the receiver B at a winding of the command relay C. If the signals in both channels (I and II or III and IV) from a single direction are the same, the currents are also equal in both windings of the relay C, and the control mechanism--the fins of the missile--is in the neutral position, i.e., in the position for straight-line flight. If one signal is greater than the other, there is a difference of current in the windings of the relay C, and therefore the fins of the rocket move accordingly. The missile changes direction until balance is again established, i.e., until its flight direction coincides with the line to the electronic facility.

In addition to the basic elements we have enumerated, the receivers on the missile can scan through a wide frequency range. The homing guidance head itself can memorize the line taken to the electronic facility, which is indispensable should the electronic facility cease emitting as a defensive measure. The missiles are also equipped with altitude fuses which cause them to explode between 15 and 30 meters above the electronic facility. Detonation causes the missile's explosive charge to explode into countless particles, and antenna systems are destroyed.

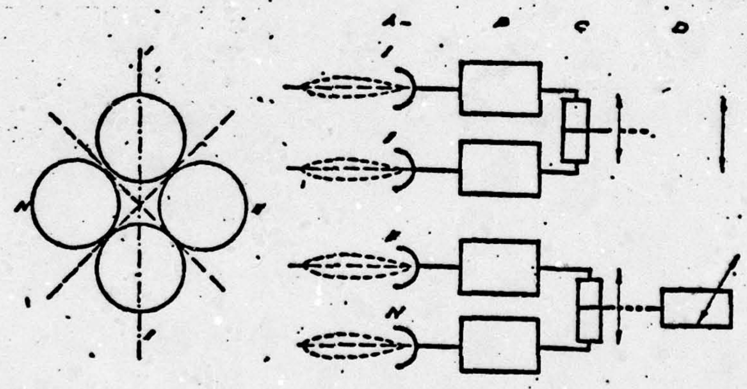


Figure 14.3. Principle of the assembly for passive homing guidance of a missile: a--quadrants (cross section of antenna beams), b--block diagram; A--antennas of quadrants I, II, III, IV; B--receivers of quadrants I, II, III, IV; C--command relay; D--control system--rocket fins.

The maximum range at which homing guidance is still possible with a particular head is obtained in the following way:

A signal of the following magnitude is received from the electronic facility at the receiver of the homing guidance head:

$$P_{prij} = (P_{el} \cdot G_{el} \cdot G_r \cdot \lambda^2)/(4\pi R)^2 \qquad (14.1)$$

in which P_{prij} = incoming signal,
P_{el} = transmitting power of the electronic facility,
G_{el} = amplification of the antenna of the electronic facility,
G_r = amplification of the antenna of the homing guidance head,
R = distance.

The minimum incoming signal is equal to the noise level of the receiver, which is adjusted upward by the safety factor γ, which ensures proper operation of the guidance system. So

$$P_{min} \geq \gamma \cdot N_{receiver\ noise} \qquad (14.2)$$

in which $1 < \gamma < n$.

The relation between the amplification G and the effective surface of the antenna A of the homing guidance head is given as

$$(G_r/A_r) = (4\pi/\lambda^2). \qquad (14.3)$$

Using the equations (14.3, 14.2 and 14.1), we obtain the expression for maximum distance

$$R_{max} = (P_{el} \cdot G_{el} \cdot A)/(4 \cdot \pi \cdot \gamma \cdot N_{receiver\ noise}). \qquad (14.4)$$

The distance obtained in this way is the maximum. For practical purposes missiles are launched later for the sake of guidance reliability.

Missiles of this type are known even from World War II. The Germans used the Max-R and Radieschen rockets against short-wave and very-short-wave transmitters.

Several kinds of missiles of this type are manufactured today. The Corvus missile (United States) is designed to attack electronic facilities on ships; its range is about 120 km. Another missile of this kind is the GAM-57 Crossbow, with a range of about 320 km, a launch weight of 907 kg, a velocity of 310 meters/second, and a solid-fuel motor. The third missile in the family is the Longbow, which is launched from an airplane in the manner described in Figure 14.2 at a distance from the target that is safe for the aircraft. A range of about 800 km has been achieved.

In the Vietnam war the Shrike missile, which has a range between 50 and 75 km and an accuracy of ±15 meters was used against electronic facilities from the A-4, A-6, A-7 and F-4 airplanes. The rocket homes on pulsed radars, whose pulse frequency is between 390 and 1,550 pulses/second and have an operating frequency between 3,900 and 6,200 MHz. Solid fuel is used for propulsion. Should the radar cease to operate during homing guidance, the missile continues its flight along the memorized trajectory. The use of these missiles

in the Vietnam war showed that their weak point was their short range and high sensitivity to reflections of the radar beam from structures in the vicinity of the radar station.

XV CONSTRUCTION CONCEPTION OF ELECTRONIC EQUIPMENT AND ITS EFFECT ON COUNTERMEASURES

In the preceding chapters it was seen that through the broad spectrum of electronic countermeasures one can more or less effectively affect all the performances of electronic equipment and thereby prevent its application in the decisive moment.

To what extent electronic equipment will be sensitive to electronic countermeasures depends not only on the nature of its use but also on its construction conception. In other words, this means that a simple electronic equipment can be disabled by relatively simple electronic countermeasures. On the other hand, the operation of that electronic equipment where measures against electronic defense were taken into consideration still during its design will be much more difficult to disable by electronic countermeasures and this effect will not always be one hundred percent. Below we shall give certain recommendations which should be kept in mind in the design of the construction conception of an installation so as to render it as least sensitive as possible to the heretofore known electronic countermeasures.

15.1. COMMUNICATIONS EQUIPMENT

The construction conception of communications equipment must be such that it enables:

a) rapid and accurate change in the frequency within a wide frequency range. For this purpose, very suitable are frequency synthesizers with conditional marking of the channel;

b) a change in the output transmitting power depending on the required range;

c) increase in the output transmitting power, in case of jamming, for the sake of increasing the ratio "intelligent signal--interference";

d) use of such types of modulation which render simultaneous encoding of information impossible;

e) time compromising of information so that emitting would be done within the shortest possible time;

f) application of antenna systems with directed radiation and minimal side fans;

g) rapid conversion from one modulation to another;

h) application of optimal receiver with variable permeable width and maximal signal--noise ratio;

i) conditional marking of frequency divisions on the installations and the accessory measuring equipment.

The installations must be built so that they guarantee maximum reliability both of the component parts and the installation as a whole.

15.2. RADAR EQUIPMENT

a) Construction of antenna system must be such that it enables accurate determination of location of the target within the shortest possible time. Therefore, and to improve the signal--interference ratio, the antenna system must have:

- as directed as possible radiation diagram;

- radiation diagram with minimal side fans;

- multi-fan antenna radiation diagram in radars which search a large sector by elevation;

- rapid turning of antenna or

- arhythmical preprogrammed rapid searching of the space with narrow antenna beam, and

- radiation of electromagnetic energy into the space only when this is necessary for detection; and during the remaining time - operation of quality artificial antennas without parasytic radiation.

b) The wave-conducting radar system must be such that:

- standing waves are minimal, and

- couplings of individual wave-conducting sections are done with quality so that no paralytic radiation occurs on them.

c) Radar transmitter must have:

- high output transmitting power due to the high signal--noise ratio;

- variable output transmitting power, depending on the distance of observation and the signal--interference ratio;

- permanently or periodically variable pulse frequency;

- variable pulse length;

- use of transmitting pulse of such a shape whose reproduction is not easy, and

- arhythmic preprogrammed change in transmitting frequency from pulse to pulse.

d) Beside this, the radar receiver must have a maximal signal-noise ratio, it should have integrated all heretofore known defense measures against radar countermeasures (from special wheels to

optimal reception technique).

e) All scales, divisions, and designations on installations as well as on accessory measuring equipment must be in arbitrary units. This is expressly important for data on frequency and sensitivity, i.e. for data which are obtained by radio reconnaissance,

f) The crew manning the installation or the system must be well acquanited with the effects produced by electronic countermeasures on their particular installation and with the effectiveness of electronic defense measures.

g) The installation must be so constructed that rapid change in position is impossible.

h) Above all, the entire production of the installation must be such that it guarantees maximal reliability both of the component parts as of the installation as a whole.

AD-A083 358 FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON AFB OH F/G 17/4

ELECTRONIC COUNTERMEASURES,(U)

AUG 79 A RAZINGAR

UNCLASSIFIED FTD-ID(RS)T-0498-79 NL

5 OF 5

AD

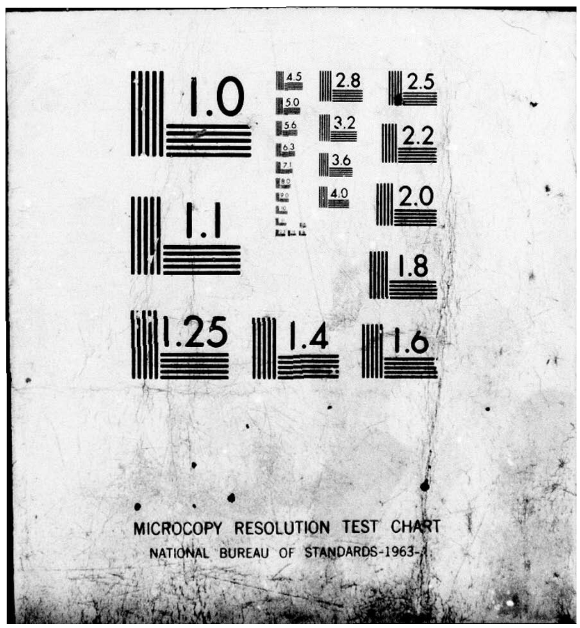
AD 83358

END

DATE FILMED

5-80

DTIC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
5.0
5.6
6.3
7.1
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Some ground and airborne electronic countermeasure devices used by the Armed Forces of the USA*

naziv	vrsta	proizvođač	ugrađen na avion	napomena
1	2	3	4	5
	a Uređaji za elektronsko izviđanje i analizu			
AN/ALA—5	analizator impulsa b	0	RB-66 C	
AN/ALA—6	analizator impulsa	Hallicrafters	B-52, RB-66 C	
AN/ALD—2	goniometar c	Rodale/Babcock	F-4B, S-2D/E	
AN/ALD—4	komplet za elektronsko d izviđanje	Melpar	RB-47, B-52	
AN/ALD—5	komplet prijemnika e	Raytheon	RC-135B	
AN/ALD—28	gonio-metarski komplet f	Babcok		
AN/ALD—51	gonio-metar g	Sanders		
AN/ALD—6XN—1	gonio-metar upozorenja h	LTV		
AN/ALQ—61	komplet za izviđanje i i ometanje	Airborne Instruments Lab.	RF-4B/C RF-111A RA-5c, A-6A, E-2A	
AN/ALR	komplet prijemnika	Hazetline	EC-121	
AN/ALR—2	komplet prijemnika	Avco Corp.	F-111	
AN/ALR—8	komplet prijemnika	Raytheon	Morn. avij.	
AN/ALR—12	prijemnik j	Sylvania	B-58	
AN/ALR—15	komplet prijemnika	American Electronic Lab.	A-6A A-7A	
AN/ALR—17	komplet prijemnika za k radarske frekvencije	Electronic Specialty	FR-4C RB-66, B-52	USA F
AN/ALR—18	komplet prijemnika	General Electr.	B-52H	
AN/ALR—19	komplet prijemnika	RCA	B-52, B-66	USA F
AN/ALR—20	panoramski prijemnik l	Electr. Specialty	EA-1F, P-3A	
AN/APA—144	analizator signala m	Loral	EC-121H	
AN/APR—9B	prijemnik radara n	Hallicrafters	B-47, B-52, RB-66	

*data from "Wehr und Wirtschaft," No. 5/1969, pp. 301-304

Key: 1 - Designation; 2 - type; 3 - Manufacture; 4 - Integrated inaairplane; 5 - remark.
a - Devices for electronic reconnaissance and analysis; b - pulse analyzer; c - gonioemeter; d - set for electornic reconnaissance; e - receiver set; f - goniometer set; g - goniometer; h - warning goniometer; i - set for reconnaissance and jamming; j - receiver; k - receiver set for radar frequencies; l - panoramic receiver; m - signal analyzer; n - radar receiver.

1	2	3	4	5
AN/APR—14	prijemnik a	Raytheon	B-52	
AN/APR—17	izviđački komplet prijemnika	Loral Corp.	B-52	
AN/APR—18	izviđački komplet prijemnika	Motorola	RA-5C	
ER—142	gonio-metar	ITEK/Applied Technology	F-100, F-105 RF-4C	USA F
AN/ASR—5	d automatski komplet za izviđanje	Sylvania	RC-15B	USA F
AN/APR—27	upozorenje od ispaljene prve rakete	Magnavox	F-4B	mornarica
AN/APR—36	upozorenje od radara	Itek/App. Techn.	F-105	
AN/APR—37	upozorenje od radara	Itek/App. Technol.		
AN/APS—105	upozorenje od radara	Dalmo-Victor	B-52	USA F
AN/APS—107	upozorenje od radara	Bendix Pacific	F-105, F-4D	
	g Radarski uređaji protivdejstava:			
AN/APA—159	radar	Hazetline	EC-121D/H	
AN/APA—162	kartografski radar	Goodyear		
AN/APD—4	radarski uređaj	ITT Fed. Electr.	B-47, B-52, B-66	
AN/APH—2	obeležavajući uređaj	NA/Autonetics	B-52	
AN/APQ—55	radar za bočno osmatranje	Goodyear	RF-4C	
AN/APQ—56	kartografski radar	Westinghouse	RB-47	
AN/APQ—59	radar za bočno osmatranje			
AN/APQ—73	radar za bočno osmatranje sa sintetskom antenom	Goodyear	SR-71	
AN/APQ—102	radar za bočno osmatranje	Goodyear/Varian	RF-4B/C/D	
AN/APQ—108XA1	kartografski radar	Condustron	SR-71	
AN/APQ—133	radar za bočno osmatranje	Motorola	AC-119	
AN/APS—73	radar za bočno osmatranje	IBM/Goodyear	HU-16B	

Key: a - receiver; b - reconnaissance receiver set; c - ~~gonio-~~ goniometer; d - automatic reconnaissance set; e - warning from fired first rocket; f - warning from radar; 9 g - radar countermeasure devices; h - radar; i - cartographic radar; j - radar installation; k - marking device; l - radar for side observation; m - radar for side observation with s synthetic antenna; n - radar for side observation; o - radar for side observation.

1	2	3	4	5
AN/APS—88A	a radar za bočno osmatranje	Texas Instruments/ Belock	S-2D/E	
AN/APS—94	b radar za bočno osmatranje	Motorola	OV-1B	
AN/APS—95	c avionski radar	Hazeltine	EC-121, RC-121	
	d Uređaji protivdejstava u kontejnerskom sistemu:			
AN/ALQ—87/V	e kontejner elektronskog protivdejstva	General Electric	F-106, F-111A	
AN/ALQ—101	kontejner elektronskog protivdejstva	Westinghouse	FB-111A, F-4	e razvoj
		f trenažeri:		
AN/ALQT11	g trenažer ometanja	ITT Gilfillan	B-47, B-52, B-58	
AN/ALQT3/4	h simulator ometanja	Reflectone	B-52, B-58	
AN/ALQ—71	i komplet aktivnog ometača šumom	Hughes	F-101, T-33, B-52 B-57, RB-66 F-105D/F	USA F
AN/ALQ—72	j komplet aktivnog ometača	Hughes	F-105D/F, T-33 F-101, B-57, RB-66	USA F
AN/ALQ—76	k šumni ometač	Douglas/Raytheon	A-4, EA-6A	mornarica
AN/ALQ—78	l prijemnik/ometač	Loral	P-3C	mornarica
AN/ALQ—80	m šumni ometač	Hallicrafter	CV-2, OV-1	mornarica
AN/ALQ—86	n uređaj za protivdej.	Bunker/Ramo	EA-6A	
AN/ALQ—88	uređaj protivmera	Sanders Ass.		
AN/ALQ—98	o aktivni ometač	General Instruments		
AN/ALQ—100	aktivni ometač	Sanders	A-4, A-6, A-7	mornarica
AN/ALT—6A/B	p predajnik ometanja		B-47, B-52 B-57, B-66	
AN/ALT—13	predajnik ometanja	Hallicrafters	B-47, B-52 B-57, B-66	

Key: a - radar for side observation; b - radar for side observation; c - airplane radar; d - countermeasure devices in container system; e - electronic countermeasure container; f - trainers; g - jamming trainer; h - jamming simulator; i - set of active jammer by noise; j - active jammer set; k - noise jammer; l - receiver/jammer; m - noise jammer; n - countermeasure device; o - active jammer; p - jamming receiver.

1	2	3	4	5
AN/ALT—15	a predajnik ometanja	Hallic./Sperry	B-47, B-52 B-57, B-6c	
AN/ALT—16	predajnik ometanja	Hallicrafters	B-47, B-52 B-57, B-66	
AN/ALT—21A	predajnik ometanja	Litton	avioni/brodovi	
AN/ALT—22	predajnik ometanja	General Electric	B-52	
AN/ALT—27/V	b uređaj ometanja	Litton Systems		
AN/ALT—28	c predajnik ometanja	Hallicrafters		
	d Uređaji za upozorenje:			
AN/ALR—21	e od ispaljivanja PA rakete	Texas Instruments	B-52	USA F
AN/ALR—23	od ispaljivanja PA rakete	Avco Corp.	F-111A, B-52	USA F
AN/ALR—31	f goniometar ispaljene PA rakete	Loral Corp.	F-105	USA F
AN/APR—23B	g pasivni goniometarski radar	Melpar	A-4B	
AN/APR—25	h upozorenje i goniometarski radar	Itec/Applied Technology	F-100F, F-105 F-4C, RF-4c, C-47 RA-5C, C-123 C-130, C-141	USA F
AN/APR—26	od ispaljivanja PA rakete	Itec/Applied Technology	F-100, F-105 RF-4C, RA-5C C-47, C-123 C-130, 141	USA F
	i Uređaji za zapisivanje snimljenih signala:			
AN/ALH—4	j magnetofonski snimači sistema	Ampe X	B-52	
AN/ALH—6	magnetofonski snimači sistema	Bunker-Ramo		

Key: a - jamming transmitter; b - jamming device; c - jamming transmitter; d - warning devices; e - re firing of AA rocket; f - goniometer of fired AA rocket; g - passive goniometer radar; h - warning and goniometer radar; i - devices for recording of signals read; j - magnetic tape system readers.

1	2	3	4	5
	Uređaji za pasivna protivdejstva:			
AN/ALE—1	izbacivač dipola	Webcor		
AN/ALE—2	izbacivač dipola	Haber Corp.		
AN/ALE—4	izbacivač dipola	Ryan		
AN/ALE—5	izbacivač dipola	Ryan		
AN/ALE—18	izbacivač dipola	Applied Science	A-6A, S-2D	
AN/ALE—24	krilni izbacivač dipola	Lundy Electronics		
AN/ALE—25	raketni izbacivač dipola	Boeing	B-52H	
AN/ALE—28	izbacivač dipola	General Dynamics	F-111A	
AN/ALE—29	izbacivač dipola	Goodyear/Tracor	F-111	
AN/ALE—30	izbacivač dipola	Lundy Electronics	A-6A	
AN/ALE—32	izbacivač dipola	Lundy Electronics	EA-6A	
	Uređaji za aktivna protivdejstva:			
AN/ALQ	komplet ometača	Hyghes Aircraft	F-101, F-102 F-106	
AN/ALQ—16	komplet aktivnog ometača	Sylvania	B-58	
AN/ALQ—17	aktivni ometač	Hughes/Gen. Electr.		
AN/ALQ—19	aktivni ometač	Sanders Ass.	A-4	
AN/ALQ—23	aktivni ometač	Webcor	A-4	
AN/ALQ—28	aktivni ometač	Loral		
AN/ALQ—35	aktivni ometač	Litton		razvoj
AN/ALQ—37	aktivni ometač	American Electronic		razvoj
AN/ALQ—41	aktivni ometač X područja	Sanders/Raytheon	A-6A	
AN/ALQ—46	aktivni ometač	Raytheon		
AN/ALQ—49	aktivni ometač	Sanders Ass.	A-4, A-3, RA-5C	mornarica
AN/ALQ—51	aktivni ometač S područja	Sanders Ass.	A-3, A-6A, A-4 RA-5C, RF-101	
AA/ALQ—53	aktivni ometač	Loral/Bunker/Ramo	EA-6A	mornarica
AN/ALQ—55	akt. ometač šumom	Sanders Ass.	A-3D, EA-6A RA-5C	mornarica
AN/ALQ—58	aktivni ometač	Litton	E-2A	
AN/ALQ—59	kompl. akt. ometanja	Hallicrafters	B-52, F-105F	USA F
AN/ALQ—70	kompl. akt. ometanja	Raytheon	RC-135A	

Key: a - devices for passive countermeasures; b - dipole ejector; c - wing dipole ejector; d - rocket dipole ejector; e - devices for active countermeasures; f - jammer set; g - active jammer set; h - active jammer; i - a active jammer X region; j - active jammer S region; k - under development; l - Navy; m - active jammer by noise; n - USAF.

REFERENCES

1. L. N. RIDENOIR, RADAR SYSTEM ENGINEERING, Radiation Laboratory Series, br. 1., Mc. Graw Hill, N. Y. 1947.
2. D. E. KERR, PROPAGATION OF SHORT RADIO WAVES, Radiation Laboratory Series, br. 13., Mc. Graw Hill N. Y. 1951.
3. W. M. CADY, RADAR SCANNERS AND RADOMES, Radiation Laboratory Series, br. 26. Mc. Graw Hill N. Y. 1948.
4. E. EASTWOOD: AERIAL INVESTIGATIONS USING NATURAL NOISE SOURCES The Marconi Rewiev, Vol. XXIII, br. 136. Chelmsford, England, 1960.
5. R. S. RAVEN, AIRBORNE RADAR, Van Nostrand Co. N. Y. 1961.
6. Commandant SHÜRR: LES CONTRE-MESURES ÈLÈCTRONIQUES, Force Aériennes Francaises br. 1., 1961.
7. CONTROMISURE ELETTRONICHE, Aeronautica Militare, 1961.
8. A. POŽEG: ELEKTRONSKO OMETANJE I MERE PROTIV ELEKTRONSKOG OMETANJA, prilog Vazduhoplovnog glasnika, 1961.
9. H. MAGNUSKI: JAMMING OF COMMUNICATION SYSTEM USING FM, AM AND SSB MODULATION, IRE Trans. MIL-5 F1/1961.
10. M. SKOLNIK: INTRODUCTION TO RADAR SYSTEMS, Mc. Graw Hill N. Y. 1962.
11. К. ТРОФИМОВ: ПОМЕХИ РАДИОЛОКАЦИОННЫМ СТАНЦИЯМ, ДОСААФ, МОСКВА, 1962.
12. DAVID K. BARTON: RADAR SYSTEM ANALYSIS, Prentice Hall Inc. 1963.
13. Р. ШЛЕЗИНГЕР: РАДИОЕЛЕКТРОННАЯ ВОЙНА, превод са енгл. ВОЕНИЗДАТ, Москва, 1963.
14. ALEKSANDER I. PALI: KRIEG IM ATHER, Deutscher Militärverlag, Berlin, 1965.
15. DAVID K. BARTON: RADAR SYSTEM PERFORMANCE CHARTS, IEEE Trans. MIL-9, 1965.
16. GUIDO V. BUEHLER: ELEKTRONISCHE GEGENMASSNAHMEN UND GEGEN-GEGENMASSNAHMEN, Flugwehr und Technik, 12/1965.
17. W. CHURCHILL: DRUGI SVETSKI RAT, tom I—VI, Prosveta, Beograd.
18. СЛУЦКИИ и др.: ОСНОВЫ РАДИОЛОКАЦИИ, СОВ. РАДИО, 1965.
19. Г. М. ВИШИН: СЕЛЕКЦИЯ АВИЖУЩИХСЯ ЦЕЛЕЙ, ВОЕНИЗДАТ, МОСКВА, 1966.
20. VOJNA ENCIKLOPEDIJA, tom III, Beograd, 1966.
21. В. В. ДРУЖИНИНА редактор: СПРАВОЧНИК ПО ОСНОВАМ РАДИОЛОКАЦИОННОЙ ТЕХНИКИ, ВОЕНИЗДАТ, МОСКВА, 1967.
22. Ю. А. МИЩЕНКО: РАДИОЛОКАЦИОННЫЕ ЦЕЛИ, ВОЕНИЗДАТ, Москва, 1966.
23. Д. Б. КАНАРЕЙКИН, Н. Ф. ПАВЛОВ, В. А. ПОТЕХИН: ПОЛАРИЗАЦИЯ РАДИОЛОКАЦИОННЫХ СИГНАЛОВ, Москва, СОВ. РАДИО, 1966.
24. Leo BRANDT: ZUR GESCHICHTE DER RADARTECHNIK IN DEUTSCHLAND UND GROSSBRITANIEN, Ortung und Navigation, 4/1967.

25. RAJMOND S. BERKOWITZ: MODERN RADAR, John Wiley N. Y. 1967.

26. A. RAZINGAR: OMETANJE RADARSKIH UREĐAJA I PROTIVMERE, VTG, 6/1968.

27. H. J. FRIEDMAN: JAMMING SUSCEPTIBILITY, IEEE Trans. AES-1, jul 1968.

28. Я. И. ФДЕНОВ: СПОСОБЫ ПРОРЫВА ПРО, ВЕСНИК ПВО, 4/968.

29. Alfred PRICE: HERRSCHAFT UBER DIE NACHT, Bertelsman Sachbuchverlag, 1968.

30. Ю. Г. СТЕПАНОВ: ПРОТИВРАДИОЛОКАЦИОННАЯ МАСКИРОВКА, СОВ. РАДИО, Москва, 1968.

31. С. А. ВАКИН и Л. Н. ШУСТОВ: ОСНОВИ РАДИОПРОТИВОДЕЙСТВИЯ И РАДИОТЕХНИЧЕСКОЙ РАЗВЕДКИ, СОВ. РАДИО, Москва, 1968.

32. С. Г. ЗУБКОВИЧ: СТАТИСТИЧЕСКИЕ ХАРАКТЕРИСТИКИ РАДИОСИГНАЛОВ ОТРАЖЕННЫХ ОТ ЗЕМНОЙ ПОВЕРХНОСТИ, СОВ. РАДИО, Москва, 1968.

33. J. M. CRISPIN i dr.: METHODS OF RADAR CROSS-SECTION ANALYSIS Academic Press N. Y. 1968.

34. Ю. М. КАЗАРИНОВ, редактор: РАДИОТЕХНИЧЕСКИЕ СИСТЕМИ, СОВ. РАДИО, Москва, 1968.

35. R. W. KREUTEL: THE MEASUREMENT OF GAIN AND NOISE TEMPERATURE OF A SATELITE COMMUNICATION EARTH STATION, MICROWAVE JOURNAL No. 10, 1969.

36. И. А. БОЛШАКОВ: ВЫДЕЛЕНИЕ ПОТОКА СИГНАЛОВ ИЗ ШУМА, СОВ. РАДИО, Москва, 1969.

37. Л. Г. ШИРШЕВ: ИОНИЗИРУЮЩИЕ ИЗЛУЧЕНИЯ И ЕЛЕКТРОНИКА, СОВ. РАДИО, Москва, 1969.

38. Я. А. ШНЕЙДЕРМАНОМ: НОВЫЕ РАДИОПОГЛОЩАЮЩИЕ МАТЕРИАЛИ ЗАРУБЕЖНАЯ РАДИОЕЛЕКТРОНИКА бр. 6 год. 1969 (стр. 101—123).

39. ELEKTRONISCHE KAMPFFUHRUNG AUS DER LUFT, Soldat und Technik br. 8/1968 (454—455)

40. MILITARISCHE SATELLITEN, Soldat und Technik br. 12/1968 (664—669).

41. CHARLES F. MEYER: ELECTROMAGNETIC EFFECTS OF NUCLEAR WEAPONS, Frequency Technology vol. 7. br. 5/1969.

42. ELEKTRONISCHE KAMPFFUHRUNG, Wehr und Wirtschaft br. 5/1969 (297—304).

43. NACHTSICHTGERATE DER U. S. STREITKRAFTE, Wehr und Wirtschaft br. 10 i 11/1969 (564—568 i 623—624).

44. ZIELFLUGKÖRPER UND AUFKLÄRUNGSFLUGKÖRPER, Soldat und Technik br. 2, 1969, (68—74).

45. WO BLEIBT DER FLAK-PANZER? Wehr und Wirtschaft br. 2/1970 (86—88).

46. U. GELPE: MENSCHLICHE UND ELEKTRONISCHE AUGEN IM SEEKRIEG, Soldat und Technik 2/1970 (84—87).

47. Patent, francuski, br. 131775 kl. CO8d od 2. II. 1963.

48. Patent SAD br. 3. 185986 kl. 343—18 od 25. V. 1965.

49. Patent Zap. Nemačke, br. 977525 kl. 24 a[4] 48/63 (GolS, Holq) od 24. IV 1966.

50. Patent Zap. Nemačke, br. 977525 kl. 25 a[4] 48/63 (GolS, Holq) od 24. XI. 1966.

DISTRIBUTION LIST

DISTRIBUTION DIRECT TO RECIPIENT

ORGANIZATION		MICROFICHE	ORGANIZATION		MICROFICHE
A205	DMATC	1	E053	AF/INAKA	1
A210	DMAAC	2	E017	AF/RDXTR-W	1
B344	DIA/RDS-3C	9	E403	AFSC/INA	1
C043	USAMIIA	1	E404	AEDC	1
C509	BALLISTIC RES LABS	1	E408	AFWL	1
C510	AIR MOBILITY R&D LAB/FIO	1	E410	ADTC	1
C513	PICATINNY ARSENAL	1		FTD	
C535	AVIATION SYS COMD	1		CCN	1
C591	FSTC	5		ASD/FTD/NIIS	3
C619	MIA REDSTONE	1		NIA/PHS	1
D008	NISC	1		NIIS	2
H300	USAICE (USAREUR)	1			
P005	DOE	1			
P050	CIA/CRB/ADD/SD	2			
NAVORDSTA (50L)		1			
NASA/NST-44		1			
AFIT/LD		1			
LLL/Code L-389		1			
NSA/1213/TDL		2			

DAT

FILM